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THE UNIVERSITY OF ALBERTA

SURVEY OF HEALTH-RELATED ENVIRONMENTAL FACTORS AT INDOOR SWIMMING POOL FACILITIES

by

CHRISTINE LAVERDURE

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
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THE DEGREE OF MASTER OF SCIENCE

IN

ENVIRONMENTAL SCIENCE
DEPARTMENT OF CIVIL ENGINEERING

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Survey of Health-Related Environmental Factors at Indoor Swimming Pool Facilities** submitted by **Christine Laverdure** in partial fulfillment of the requirements for the degree of **Master of Science** in **Environmental Science**.

....
Dr. Steve E. Hrudey, Supervisor

Daniel W. Smith
Dr. D.W. Smith

....
Dr. J. Plambeck

Date: April 18/91

Pour la petite fille de douze ans
qui avait un rêve,

pour Sylvain
avec copieux remerciements

et

pour mes parents: Madeleine et Paul-Emile;
mes quatre soeurs: Lise, Françine, Danielle, Odette;
et mes deux frères: Luc et Guy
pour leurs encouragements
malgré la distance...

ABSTRACT

In recent years, there has been a renewed interest in aquatic recreation. Swimming pools are used by millions of people for sports, recreation, therapy and the promotion of good health through exercise. However, there have been a number of recent cases of health complaints by indoor pool users and operational staff.

To achieve a better understanding of the apparent problems an extensive evaluation of environmental factors was performed along with a parallel study of the character, frequency and extent of health problems encountered by patrons and staff at three different swimming pool sites. Monitoring was performed for: aldehydes, chlorine species, trihalomethanes (THMs), total kjeldahl nitrogen (TKN), total organic carbon (TOC), non-target organic chemicals, as well as aqueous and aerosolized microbial activity. Chemical analyses of the air phase, including aldehyde measurements and grab-sampling were also performed.

Formaldehyde and acetaldehyde were found to be present in some pool waters at levels up to 3 mg/L and 0.8 mg/L, respectively. Formaldehyde is well recognized for its irritant potential but air phase concentrations of formaldehyde could not be detected. Free available chlorine and combined chlorine residuals were found to be out of regulatory compliance at all sites at one time or another. Better characterization and monitoring of chlorine species will have to be performed in order to differentiate between the inorganic chloramines and organic chlorine compounds.

In addition, the participating swimming pools were found to present higher heterotrophic plate counts (HPC) than allowable under regulation. The swimming pool water also supported the presence of total coliforms (TC)

and fecal coliform (FC), as well as *Pseudomonas aeruginosa* on some occasions. The problems in meeting the Provincial HPC regulation showed a pattern of increase over the duration of the day, likely in response to bather load.

There were strong correlations observed between aldehydes and TKN, as well as between TOC and TKN. HPC were also correlated to TOC. These findings suggest that water quality management should deal both with the reduction of disinfection by-product precursors and with microbial growth substrates.

Because chemical analyses performed on the air phase were unable to detect any of the target aldehydes their role in causing irritant problems is uncertain. Additional air phase work should include analysis of THMs, chloramines and oxidants. Aerosol monitoring of the air phase revealed the presence of some low levels of Gram-negative species which have been reported to cause allergy symptoms at higher levels. More exhaustive aerosol monitoring will have to be performed to assess the importance of aerosol formation as a possible causative agent of the health effects reported.

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My foremost thanks are extended to my graduate program supervisor Dr. Steve E. Hrudey for his helpful guidance, encouragement and constructive criticism. Also, my sincere appreciations are extended to Dr. Ken Yoshida and Dr. C.L. Soskolne from the Department of Health Services Administration & Community Medicine, for valuable comments on the experimental air sampling part of this project and directing the swimming pool users survey, respectively. I also thank, Mr. Brian Sullivan chairman of the Alberta Association for Recreational Facilities Personnel for coordinating the contacts with the different sites participating in this study, as well as, the many operational staff who were extremely helpful. As well, I thank Mr. John Shaw from Alberta Health for his helpful comments.

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LIST OF ABBREVIATIONS

AOX	Adsorbable Organic Halogen
APCI	Atmospheric Pressure Chemical Ionization
ALS	Automated Liquid Sampler
atm	atmosphere
BEA	N-Benzylethanolamine
°C	degree Celcius
cm	centimetre
DBP	1,3-Dibromopropane
DCM	Dichloromethane
DNPH	2,4-Dinitrophenylhydrazine
DPD	N,N-diethyl-*p*-phenylenediamine
ECD	Electron Capture Detector
EPA	Environmental Protection Agency
FAC	Free Available Chlorine
FAS	Ferrous Ammonium Sulfate
FC	Fecal Coliforms
FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared
g	gram
GAC	Granular Activated Carbon
GC	Gas Chromatograph
GC/MSD	Gas Chromatography/ Mass Selective Detection
h	hour
HP	Hewlett Packard

(continued...)

LIST OF ABBREVIATIONS

HPC	Heterotrophic Plate Counts
HPLC	High Performance Liquid Chromatography
IBA	Immediately Before Analysis
IDLH	Immediately Dangerous to Life and Health
IR	Infrared
KHP	Potassium Hydrogen Phthalate
L	Litre
$\mathrm{LD}_{\mathrm{LO}}$	Lethal Dose Low
$\mathrm{LD}_{\mathrm{LO\ (woman)}}$	Lethal Dose Low for Woman
LOD	Limit of Detection
LSC	Liquid Sample Concentrator
M	Molar
m	metre
m^3	cubic metre
mm	millimetre
MBTH	3-Methyl-2-benzothiazolane hydrazone
MDL	Method Detection Limit
µg	microgram
mg	milligram
min	minute
µL	microlitre
mL	millilitre
MS	Mass Spectrometry
MSD	Mass Selective Detection

(continued...)

LIST OF ABBREVIATIONS

N	Normal
ng	nanogram
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PEM	Personal Exposure Monitoring
PFBOA	O-(2,3,4,5,6-pentafluorobenzylhydroxylamine)
PQL	Practical Quantitation Limit
ppb	parts per billion
ppm	parts per million
ppmv	parts per million volume
ppt	parts per trillion
RTECS	Registry of Toxic Effects of Chemical Substances
SP	Spectra Physics
STEL	Short-Term Exposure Limit
TC	Total Coliforms
TC_{LO}	Toxic Concentration Low
THM	Trihalomethane
THMs	Trihalomethanes
TKN	Total Kjeldahl Nitrogen
TLV	Threshold Limit Value
TWA	Time Weighted Average
TIC	Total Ion Chromatogram
TOC	Total Organic Carbon

(continued...)

LIST OF ABBREVIATIONS
(CONCLUDED)

USA	United States of America
USA-ACGIH	U.S.A. American Conference of Governmental Industrial Hygienists
USEPA	U.S. Environmental Protection Agency
UV	Ultraviolet

1. INTRODUCTION

Participation in sports and other recreational and social activities has been particularly emphasized in recent years. With this new emphasis, an increasing number of individuals are opting for aquatic activities (Griffiths and Wilkinson 1986, Mandojana and Letot 1987). Swimming pools are used by millions of people for sports, recreation, therapy and the promotion of good health through exercise (Decker 1988, Sarnaik et al. 1986). The term swimming pool now also includes a variety of recreational facilities, such as wave pools, spas or whirlpools (jacuzzi) and water flume slides. These innovations in aquatic recreational technology, in combination with a heavier load of bathers, pose new challenges to the management of indoor public swimming pool facilities (Shaw 1986). These changes have also involved increasing managerial concern for water disinfection and control of air quality at indoor pools.

1.1 Background

Concern for operational costs at indoor public swimming pools has prompted management to promote greater energy efficiency. Programs have often been implemented through recirculation of the indoor air at the expense of reduced fresh make-up air from outdoors (Lawrence 1990, Shaw 1986). Closer control of disinfectant chemical dosages has also been implemented (Penny and Winter 1984).

These changes have apparently been accompanied by increasing health complaints by facility users and operational staff. Specifically, users and staff have apparently experienced health symptoms including headaches, nausea, lethargy and irritation of the eyes, nose and throat, coughing and other symptoms associated with allergies and/or asthma. In some instances, staff have taken sick leave and swimmers have stopped using the facilities. Activities at some pools had to be severely curtailed (i.e. temporary closure) until the problem was adequately addressed (Bénard et al. 1990, Christopher 1989).

Indoor air quality in non-industrial environments has become a major concern in the past ten years. Consequently, health complaints in such settings are investigated more frequently. Enclosed swimming pools represent an environment with a greater potential for problems, since these indoor facilities have high ambient temperatures and relative humidity. Indoor environments with excessive humidity can potentially contribute to increased levels of pathogenic or allergenic organisms and promotion of serious structural damage to building materials (Bénard et al. 1990). These factors, combined with an energy conservation program under reduced air exchange, yield an air quality that can give rise to increased airborne irritation problems (Bénard et al. 1990).

The circumstances which have been described for air quality in indoor public swimming pools may provide clues to the irritation problems, which have only started to receive interest.

1.2 Scope of Project

Because chemical reactions which may produce irritant by-products occur initially in the water phase, this project primarily examined the aqueous phase as well as the enclosed pool atmosphere for potential irritants. Waterborne chemicals can be volatilized and microorganisms can be aerosolized to the overlying atmosphere of indoor swimming pool enclosures (Mangione et al. 1985, Shaw 1986).

The use of chlorine for disinfection of swimming pools water is well-established for private and commercial purposes. Although some agencies have recommended alternative treatments, hypochlorite or chlorine gas are still largely used for most private pools and all larger public pools with high chlorine demands (Chiswell and Wildsoet 1989). Water research has concentrated on the quality of chlorine disinfection and the formation of disinfection by-products in drinking water. The literature on potential sources of irritants in indoor swimming pools is far more limited. According to White (1986) and the Centres for Disease Control (1976), the swimming pool water should be of the same quality as drinking water. On this premise, those disinfection by-products of interest to drinking water quality should also be relevant to indoor public swimming pools. Those which are currently receiving the greatest attention are the trihalomethanes, chloronitrogenous compounds and low molecular weight aldehydes.

Initially this project was coordinated with a pilot epidemiological survey to identify the frequency and extent of health complaints from the patrons and staff at three different swimming pool sites. These pools then became the target of an intensive sampling analytical survey for a variety of chemical and microbiological factors.

2. REVIEW OF LITERATURE

2.1 Health Problems at Indoor Public Swimming Pools

The need for disinfection of water to control epidemics and outbreaks of disease has long been recognized. Following a long evolution of water treatment processes dating as far back as the Egyptians, chlorination has been the disinfection process of choice (SDWC 1977). Disinfection of swimming pool water has been performed by analogy to the already established processes and techniques of disinfection for drinking water treatment.

The discovery of Rook in 1974, of various potentially noxious chemical compounds found in drinking water following disinfection, has raised concern about by-products formed by chlorine disinfection. Following those earlier findings, researchers have been actively engaged in identifying the sources of those disinfection by-products (DBP) and their impact on health, as well as the potential for new disinfection methods.

Most of the pools in Canada are disinfected with chlorine in the gaseous form or other chlorine releasing solid agents. Pulmonary toxicity resulting from chlorine gas is well known from industrial accidents (Mustchin and Pickering 1979). Direct chlorine toxicity is an ever-present hazard at swimming pool sites but few incidences have been reported (Decker 1988). Proper training of equipment operators is very important and knowledge in the fundamentals of pool water chemistry and use of this knowledge in operating practices can only be beneficial for maintenance programs and security at the facilities (Lowry & Associates 1989). Chlorine gas is an unlikely active chlorine species to be found in the pool atmosphere unless an accident causes a direct release of chlorine. The rapid and complete hydrolysis of chlorine gas into hypochlorous acid and hypochlorite ion at the pH levels of pool water prevent chlorine gas from occurring once chlorine has entered the aqueous phase (White 1986).

Indoor environments have also attracted the attention of the lay and scientific communities as a potential reservoir of infectious diseases (Burge 1990). Indoor infectious aerosols arise from two principal sources: human occupants and environmental conditions favouring proliferation of human pathogens. This latter source is definitely the primary culprit in a moist and warm indoor swimming pool environment (Burge 1990).

A growing number of people enjoy the benefits of public and private swimming pools for sports, leisure activities and the promotion of good health through exercise (Decker 1988). In recent years, health complaints by pool-users and staff have apparently become more frequent. Health complaints reported include the following symptoms: headache, nausea, lethargy and irritation of the eyes, nose and throat, coughing and other symptoms associated with allergies and/or asthma, usually experienced while on the premises. A limited amount of research about the causes of symptoms encountered at indoor public swimming pools has been performed. Recent sources suggest that water quality management practices may be the source of the problem (Shaw 1986).

If the water phase is the original source, problems can originate from two classes of contaminant: chemical irritants and/or irritant micro-organisms. Volatilization of chemical substances and formation of aerosols, can be enhanced by facility installations like water flumes or wave generation. These installations could enhance the transfer of the substances and micro-organisms to the overlying atmosphere.

2.1.1 Potential Chemical Irritants Present as Disinfection By-Products

Before water is introduced to the swimming pool, it contains chlorine as an anti-microbial agent and various other chemicals in trace levels. Further treatment chemicals are added upon entry of water into the pool (e.g. sanitizers, pH control agent, alkalinity control, etc.). Additional contaminants are introduced by bathers in the form of sweat, urine, skin, hair-spray, body lotion, and other excretions.

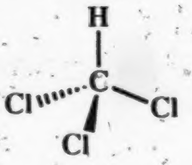
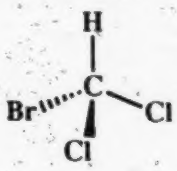
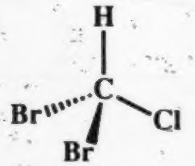
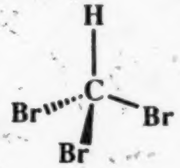
A series of complex chemical reactions occur from the admixture of chemicals, resulting in the formation of simple and complex halogenated compounds, and other organic and inorganic oxidation by-products.

2.1.1.1 Halogenated Organics

The formation of halogenated compounds, such as trihalomethanes, as disinfection by-products in the chlorination process of water containing organic contaminants is well documented (Rook 1974, 1975 and 1976, Trussell and Umphres 1978, Montgomery 1985). Swimming pool aqueous environments are no exception (Kaas and Rudiengaard 1988, Benoit and Jackson 1987, Aggazzotti and Predieri 1986, Beech et al. 1980). Trihalomethanes, and more specifically chloroform ($CHCl_3$), may pose a cancer risk in drinking water (Canadian Water Quality Guidelines 1989). There is currently sufficient evidence from experimental animals but inadequate human epidemiological evidence to classify chloroform as a human carcinogen (Aggazzotti et al. 1990 and Christman et al. 1983).

Trihalomethanes would be expected to be continuously formed in swimming pool water because of the continuous addition of organic precursors). In turn, they would be continuously lost from the water by evaporation or adsorption onto more lipophilic surfaces (Beech 1980). The former would cause transport to the air phase.

Table 2.1 Trihalomethane Structures

TRIHALOMETHANES	
 Chloroform	 Bromodichloromethane
 Dibromochloromethane	 Bromoform

In addition to the THMs species, other volatile compounds have been reported in pools by Brumen et al. (1988). These include: chlorobenzene, bromoaniline, carbon tetrachloride and N-chloroacetamide. Heavier non-volatile halogenated organic compounds would also be formed as by-products and could be measured as adsorbable organic halogen (AOX). Erdinger and Sonntag (1990) showed that swimming pool water treated first with ozonation followed by chlorination showed much lower AOX, than swimming pool water treated by chlorination as the sole method of disinfection.

Table 2.2 Properties of Volatile Halogenated Hydrocarbons Found in Swimming Pool Water. (Extended from Shaw 1986).

Compounds	Chemical Formula	Henry's Law Constant atm-m^3/mole @ 25°C	Health Effects in Air	Alberta Occupational Limits 8 h Exposure ppm	Alberta Occupational Limits 8 h Exposure mg/m^3	Alberta Occupational Limits 15 min Exposure ppm	Alberta Occupational Limits 15 min Exposure mg/m^3
Chloroform	$CHCl_3$	4.35×10^{-3}	Eye & mucous membrane irritation	10	49	50	225
Bromodichloromethane	$CHBrCl_2$	1.6×10^{-3}	Probably like chloroform	NA	NA	NA	NA
Dibromochloromethane	$CHBr_2Cl$	NA	Probably like chloroform	NA	NA	NA	NA
Bromoform	$CHBr_3$	NA	Eye irritation & lachrimation	0.5	5	1.5	16
Bromochloromethane	CH_2BrCl	NA	Eye & mucous membrane irritation	200	1060	250	1320
Carbon Tetrachloride	CCl_4	3.04×10^{-2}	Burning irritation of eyes & lachrimation	5	32	20	126
Dichloromethane	CH_2Cl_2	2.68×10^{-3}	Respiratory irritation	100	347	500	1737
1,2-Dichloroethane	CH_2ClCH_2Cl	9.77×10^{-4}	Eye, nose & throat irritation	10	40	15	60
1,1,1-Trichloroethane	CCl_3CH_3	8×10^{-3}	Eye irritation	350	1910	450	2455
Trichloroethylene	CCl_2CHCl	1.03×10^{-2}	Eye & respiratory irritation	50	269	75	403
Tetrachloroethylene	CCl_2CCl_2	1.49×10^{-2}	Burning irritation of eyes, lachrimation, nose & throat irritation	100	678	150	1017

NA: Not Available
At values above 10^{-3} atm-m^3/mole, chemicals are very readily volatilized from water.
Reference values from Howard (1990).

2.1.1.2 Organic and Inorganic Chloro-Nitrogenous Compounds

The addition of cyanuric acid (Figure 2.1) as a stabilizing agent for free chlorine in swimming pool disinfection has been widely used since the mid-1950s (Feldstein et al. 1985). Cyanuric acid can be used as its solid sodium or potassium salts, which makes it convenient for pool operators (Morgan et al. 1966). Cyanuric acid reacts with chlorine to form: mono-, di-, and trichloroisocyanurate, depending on the pH and concentration. Cyanuric acid acts as a reservoir for free chlorine in solution; that is, as free chlorine is consumed, more free chlorine is released from chlorinated isocyanurates. The equilibria expression given in Figure 2.2 illustrates this reaction. Studies in swimming pools indicate that chlorinated isocyanurates are at least as effective as chlorine in bactericidal efficiency (Linda and Hollenback 1978). Residuals of 25 to 35 ppm of cyanuric acid are favourable, while residuals in excess of 60 ppm provide no added benefits.

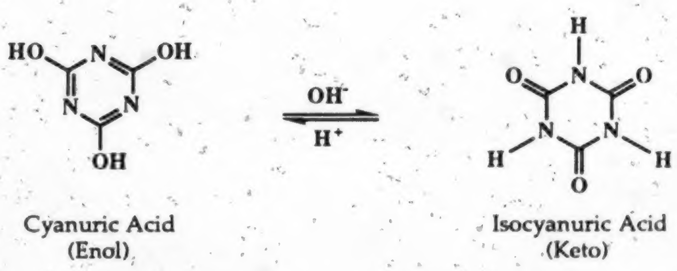


Figure 2.1 Tautomeric Forms of Cyanuric Acid.
(Adapted from Feldstein et al. 1985)

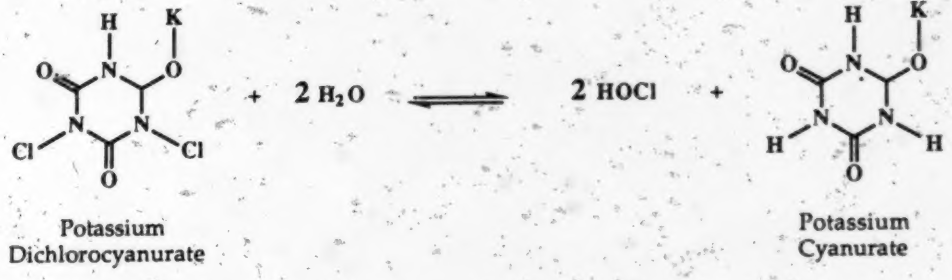


Figure 2.2 Mechanism of Release of Hypochlorous Acid from Chlorinated Cyanurate. (Adapted from Kowalski and Hilton, 1966)

As described earlier, chlorine can react with ammonia or nitrogen containing compounds originating from bathers, to form chloramines (Jessen 1986). Crabill and Lyman (1963) and many others have suggested that chloramines cause eye irritation. Furthermore, the irritating effects of both pool water and indoor pool atmosphere have generally been attributed, without much supporting evidence, to the presence of "chloramines". Shaw (1986) has questioned the general attribution of the irritating effects of both pool water and indoor pool atmosphere to chloramines.

2.1.1.3 Aldehydes

Hrudey et al. (1988, 1989) reported that chlorine reacts with various amino acids to yield various aldehydes. The specific description of pH and dosage conditions required for the reactions to occur are realistic in term of drinking water treatment conditions. Figure 2.3 shows the proposed mechanisms for the reaction causing the formation of aldehydes from amino acids reacting in chlorinated water. Under conditions of higher chlorine to amino acid ratios, Hrudey et al. have also demonstrated that nitriles can be formed.

Figure 2.4 shows the proposed mechanism for the formation of nitriles when amino acids react with excess chlorine in water. Krasner et al. (1989), found aldehydes to be the third largest detectable group of disinfection by-products (DBP) behind THMs and haloacetic acids (HAAs). Formaldehyde and acetaldehyde were reported in chlorinated waters (Krasner et al. 1989).

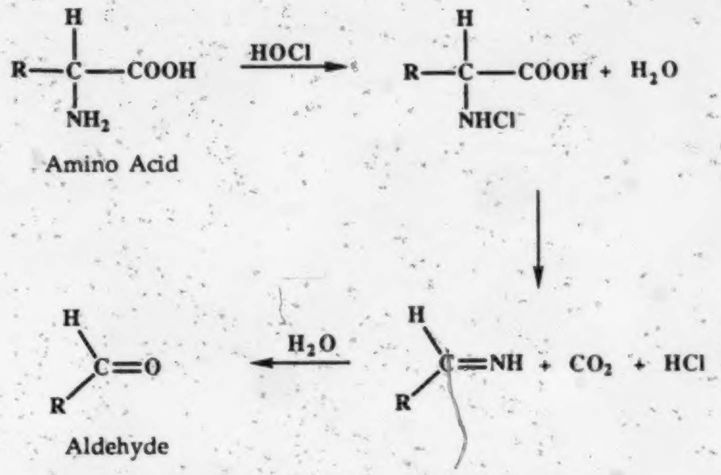

HOCl
Amino Acid
H₂O
Aldehyde

Figure 2.3 Proposed Mechanism for Aldehydes Formation from Amino Acids Reacting with Chlorine in Water.

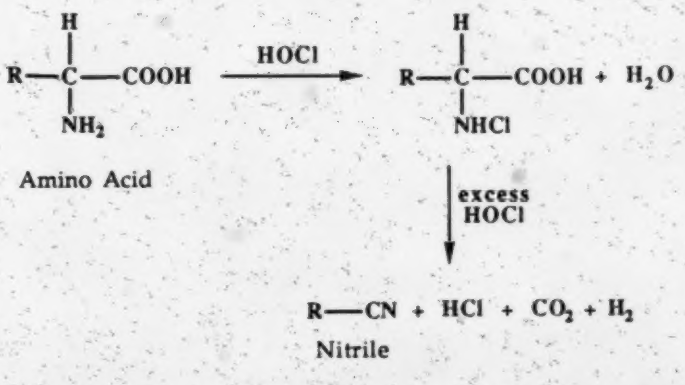

HOCl
Amino Acid
excess HOCl
Nitrile

Figure 2.4 Proposed Mechanism for Nitriles Formation from Amino Acids Reacting with Excess Chlorine in Water.

Formaldehyde is a chemical of substantial metabolic, medical, societal and industrial importance because it is a truly ubiquitous chemical (Turoski 1985, Clary et al. 1983). Formaldehyde has long been known to cause irritation and skin sensitization (Clary et al. 1983).

Table 2.3 list the effects resulting from inhalation or contact with formaldehyde (EPS 1985). Formaldehyde symptoms may occur at airborne levels as low as 0.05 ppm in very sensitive individuals. These individuals may include infants, children, the elderly, those with preexisting allergies or respiratory disease, and persons who become sensitized (Turoski 1985).

Table 2.3 Formaldehyde Exposure Effects. (Adapted from EPS 1985).

Exposure Effects	
Inhalation:	Vapour is irritating to the eyes and respiratory tract. Causes sore throat, coughing, bronchitis, nausea, gastric pain, hemorrhage and possibly death at extreme exposure.
Contact:	Contact with the skin causes irritation, tanning effect and allergic sensitization. Contact with eyes causes irritation, itching, lacrimation and possible damage in the case of large dose.

Because formaldehyde is a suspect carcinogen, long-term average exposure to formaldehyde is also of concern. Cancer risk is hypothesized to be negligible at low levels of formaldehyde exposure, and to increase in proportion to long-term average exposure (Turoski 1985). Formaldehyde is present naturally in many foods and is a metabolic product of many other foods. Exposure standards for formaldehyde are reported in Table 2.4.

The exposure standards for formaldehyde are based upon its irritant properties and lung effects, with the consideration that an exposed individual becomes acclimatized to formaldehyde exposure and can tolerate increased levels without showing adverse effects. Canadian provincial guidelines generally are similar to those of the USA-ACGIH, unless indicated otherwise (EPS 1985).

The different reported limits come from agencies of three different types: 1) regulatory body (OSHA); 2) research organization (NIOSH) and 3) organization of professional industrial hygienists (ACGIH).

Acetaldehyde is a building block in the synthesis of several organic compounds. It is rapidly and completely adsorbed and is readily metabolized. Acetaldehyde readily forms adducts with membranal and intracellular macromolecules which may be associated with its toxicity (USEPA 1987).

Acetaldehyde at high exposure appears to paralyse the respiratory muscle and thereby cause panic. It also has a general narcotic action which prevents coughing. As well, acetaldehyde causes irritations of the eyes and mucous membranes, skin and respiratory tract and accelerates heart beat (USEPA 1987, Mark et al. 1978).. When breathed in high concentration, it causes headache and sore throat. Prolonged exposure causes a decrease of red blood cells and there can also be a sustained rise in blood pressure (Mark et al. 1978). The maximum allowable concentration of acetaldehyde in air is 200 ppm (Mark et al. 1978).

Table 2.4 Recommended Exposure Limits for Formaldehyde. (Adapted from EPS 1985).

Guideline (Time)	Origin	Recommended Level	Reference
Time-Weighted Averages (TWA)			
TLV®	USA-ACGIH	1 ppm (1.5 mg/m^3)	TLV 1983
PEL (8 h)	USA-OSHA	3 ppm	NIOSH/OSHA
Occupational Standard	Canada Labour Code	2 ppm	Tartaryn 1983
Indoor Ambient Level	Proposed-USA, HUD	0.4 ppm	EST 1984
Short-Term Exposure Limits (STEL)			
STEL	USA-ACGIH	2 ppm (3 mg/m^3)	TLV 1983
Ceiling (30 min.)	USA-NIOSH	1 ppm	NIOSH/OSHA 1981
Other Human Toxicities			
IDLH	USA-NIOSH	100 ppm	NIOSH Guide
TC$_{LO}$	-	17 mg/m^3	RTECS 1979
LD$_{LO}$	-	477 mg/kg	RTECS 1979
LD$_{LO}$ (woman)	-	36 mg/kg	RTECS 1979

2.1.2 Microbial Indicators of Pollution at "Swimming Pools"

The need to disinfect "swimming pool" water has long been established. The reasons are similar to the need to disinfect drinking water: prevention of disease and epidemics through selective destruction of disease-causing organisms (Quinlan 1990, Shaw 1986, Metcalf & Eddy 1979). Several reports have associated outbreaks of enteroviral infections with community swimming pools (Lenaway et al. 1989, Strauss et al. 1988). Other disease outbreaks associated with public "heated pools" (Gregory and Schaffner 1987, Highsmith et al. 1985, Jacobson 1985, Solomon 1985, Kosatsky and Kleeman 1985) and occasionally with private whirlpools (Price and Ahearn 1988, Silverman and Nieland 1983), include reports of dermatitis folliculitis (skin lesions and rashes), otitis externa (ear inflammations), mastitis (inflammation of the breast tissue), respiratory and systemic symptoms (e.g. headache, fever, fatigue, etc...). The "heated pools" are primarily hot tubs, whirlpools and spa pools. These are usually heated above 37°C (Silverman and Nieland 1983, Berger and Seifert 1990). A majority of the literature reports disease incidents from heated pools, although some rarer incidents were contracted and reported to originate from swimming pools below 37°C (Fisher 1988, Thomas et al. 1985, Fox and Hambrick 1984).

These problems are caused by adverse water quality, often the result of the lack of inadequate disinfection (Lenaway et al. 1989, Davis 1985). Several microbial indicators for pollution of "swimming pools" have been reported in the literature. Tosti et al. (1988) have recommended to survey for: total coliforms, faecal coliforms, faecal streptococci, total bacterial counts and yeast by membrane filtration. Other authors have also surveyed for *Pseudomonas aeruginosa* , amoebae (Esterman et al. 1987) and *Mycobacterium marinum* (Fisher 1988).

2.2 Swimming Pool Public Health Regulations

The Alberta Regulation 247/85, Public Health Act in Swimming Pools stipulates the regulations to be observed by "public or semi-public swimming pool" operators. These are summarized in Appendix C. "Public swimming pool" refers to swimming pools available for public use by any segment of the public, or swimming pools operated in conjunction with educational, instructional, physical fitness or athletic programs at institutions supported in whole or in part by public funds or public subscription. "Semi-public swimming pool" refers to swimming pools provided by hotels, motels, apartment buildings, condominiums, multiple housing units, mobile home parks, trailer parks, private educational institutions or private clubs, with restricted use to the registered guests, owners, tenants, students or members and their guests. The latter category is also extended to swimming pools operated by recreational camps for use by campers and their visitors and camp personnel and swimming pools operated in conjunction with: day nursery, day camp and institutions for the care of ill, elderly or infirm, or institutions housing persons under custodial care.

In this study, the three facilities studied fall under the "public swimming pool" public health act regulations which stipulate details for licence operation, maintenance, record keeping, survey of the equipment and water quality guidelines. The following sections summarize the water quality guidelines in respect to the chemical and physical analyses, as well as the bacteriological water quality guidelines.

2.2.1 Chemical and Physical Water Quality Guidelines

The method of disinfection used must be chlorination. Swimming pools must be provided with adequate testing equipment to measure chlorine residuals, combined chlorine residuals and pH. Measuring equipment must be capable of measuring free chlorine residuals and combined chlorine residuals separately. Testing equipment must provide a range of 0 to 5.0 mg of Cl_2/L for swimming pools other than whirlpools, and of 0 to 10 mg of Cl_2/L for whirlpools. The free chlorine and pH tests shall be performed as often as necessary under normal hours of operation to permit operators to maintain the free chlorine residual and pH at levels permitted, and in no case should tests be performed at intervals of more than 4 h (Alberta Regulation 247/85).

The free chlorine residuals level should be sufficient to maintain pool water in bacteriological and chemical safe conditions at all times, and in no case should the level be less than: 0.5 mg FAC/L in any swimming pool with an operating temperature of not more than 30°C, and 1.0 mg FAC/L in any swimming pool with an operating temperature of more than 30°C. Tests for combined chlorine residuals should be conducted at least every 7 days. If on any test the combined chlorine residual is greater than 1.0 mg/L, the pool should forthwith be treated to lower it below that level. Treatment of the pool can be achieved by simply wasting some water and diluting with fresh make-up water until regulated levels are met. pH testing equipment should have a range of 6.8 to 8.2. The pH should be maintained at no less than 7.2 and no more than 8.0. Where the swimming pool is equipped with automated chemical monitoring and feeding equipment, a manual test for free chlorine residuals and pH should be conducted at least every 24 h (Alberta Regulation 247/85).

2.2.2 Bacteriological Water Quality Guidelines

At least 1 bacteriological sample of swimming pool water should be taken at intervals of not more than 7 days, and should be submitted to the Provincial Laboratory of Public Health for examination. Samples should be collected while the swimming pool is in use and should be taken from a point near an outlet in an attempt to give an accurate representation of the typical swimming pool water. Samples of chlorinated water should be dechlorinated before being sent to the Provincial Laboratory of Public Health. The water quality should be maintained so that not more than 2 consecutive water samples and not more than 15% of the series of samples taken over a 6 month period: contain more than 200 bacteria/mL, as determined by a standard 35°C plate count, show the presence of *Pseudomonas aeruginosa* in the case of a swimming pools maintained at a temperature of greater than 30°C, or show a positive test for coliform organisms in any of the five 10 mL portions of a sample when that test method is used, or the presence of coliform organisms in a 100 mL portion of a sample when the membrane filter test is used.

2.3 Chemistry of Disinfection with Chlorine

An historical note published by the National Academy of Sciences (SDWC 1977) has described the evolution of drinking water disinfection. Recorded knowledge of water treatment was found as far back as Sanskript medical lore and Egyptian inscriptions. Pictures of apparatus used to clarify water by physical mean of filtration were found as records. In 1854, Dr. John Snow found that drinking water supply was responsible for the transmission of cholera in the city of London. Snow's study was impressive because he reached his conclusions long before the germ theory of disease was established. Subsequently, research by Louis Pasteur, Robert Koch, and others, and the isolation by Koch in 1884 of the cholera causing agent, *Vibrio cholera*, the germ theory became fully established.

In the later part of the 19th century experiments to develop processes for the purification of drinking water were successful. Filtration techniques of physical and chemical nature (flocculation followed by filtration) were found to play a very important role in the removal of disease causing microorganisms. Although an acceptable level of water quality was achieved through filtration processes, the most important discovery in the technological advance of water treatment was yet to come. The introduction of chlorination after 1908 provided a cheap, reproducible method of ensuring the bacteriological quality of water (SDWC 1977).

Among chemical disinfectants, chlorination using chlorine gas is the most commonly used in Canada for municipally owned public swimming pool facilities (Wagstaff et al. 1989). Reasons are essentially economic, as it is the least expensive of the current available alternatives. In many cases it is required by regulations. Additionally, industry has had many years of experience in the handling and manufacturing of the product and associated hardware (Wagstaff et al. 1989). Some highly desirable characteristics in a disinfecting agent are summarized in Table 2.5 (adapted from Metcalf & Eddy 1979). The characteristics are given for chlorine gas, other chlorine releasing agents, chlorine dioxide and ozone.

The basic chemical reactions that chlorine undergoes in water are well known (Morris 1978). By-products formed by chlorine disinfection are being actively researched and modelled (Jolley and Carpenter 1983, Lietzke 1978). This knowledge is mostly the result of extensive drinking water research but the findings can be extended to the swimming pool management industry.

2.3.1 Reactions in Water

Chlorine gas is the most commonly used chlorine compound for municipally owned public swimming pools disinfection. When chlorine gas is added to water, two reactions take place: (2.1) hydrolysis and (2.2) ionization.

Hydrolysis of chlorine gas in water results in the formation of two acids. The week hypochlorous acid (HOCl) provides germicidal capacity, while the strongly dissociated hydrochloric acid (HCl) provides no bactericidal qualities (Coopersmith 1990). Reaction (2.1) illustrates the hydrolysis of chlorine gas:

Table 2.5 Comparison of Ideal and Actual Characteristics of Chemical Disinfectants. (Adapted from Metcalf & Eddy 1979).

Characteristic	Ideal Disinfectants	Chlorine	Sodium Hypochlorite	Calcium Hypochlorite	Chlorine Dioxide	Ozone
Toxicity to Microorganisms	Should be highly toxic at high dilutions	High	High	High	High	High
Solubility	Must be soluble in water or cell tissue	Slight	High	High	High	High
Stability	Loss of germicidal action on standing should be low	Stable	Slightly unstable	Relatively stable	Unstable, must be generated as used	Unstable, must be generated as used
Nontoxic to Higher Forms of Life	Should be toxic to microorganisms and nontoxic to man or other animals	Highly toxic to higher life forms	Toxic	Toxic	Toxic	Toxic
Homogeneity	Solution must be uniform in composition	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous
Interaction with Extraneous Material	Should not be absorbed by organic matter other than bacterial cells	Oxidizes organic matter	Active oxidizer	Active oxidizer	High	Oxidizes organic matter
Toxicity at Ambient Temperatures	Should be efficient in ambient temperature range	High	High	High	High	Very high
Penetration	Should have the capacity to penetrate through surfaces	High	High	High	High	High
Noncorrosive and Nonstaining	Should not disfigure metals or stain clothing	Highly corrosive	Corrosive	Corrosive	Highly corrosive	Highly corrosive
Deodorizing Ability	Should deodorize while disinfecting	High	Moderate	Moderate	High	High
Availability	Should be available in large quantities and reasonably priced	Low cost	Moderately low cost	Moderately low cost	Moderate cost	High cost

(2.1) $Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$

The thermodynamic equilibrium constant for this reaction is defined in Equation 2.1:

Equation 2.1 $$K = \frac{[HOCl]\,[H^+][Cl^-]}{[Cl_2]} = 4.5 \times 10^{-4} \quad \text{at} \quad 25°C$$

The large value of K indicates that large quantities of chlorine can be dissolved in water.

Ionization of the weak hypochlorous acid results in the formation of the species shown in Reaction (2.2):

(2.2) $HOCl \rightarrow H^+ + OCl^-$

The ionization constant is given by:

Equation 2.2 $$K_i = \frac{[H^+][OCl^-]}{[HOCl]} = 3.7 \times 10^{-8} \quad \text{at} \quad 25°C$$

The ionization constant for this equation varies with temperature. The quantity of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) that is present in water is called the free available chlorine (FAC). The relative distribution of both species is very important because the killing efficiency of HOCl is about 40 to 80 times that of OCl^- (Metcalf & Eddy 1979). The percentage distribution of HOCl and OCl^- at the temperature range encountered at swimming pools is illustrated in Figure 2.5.

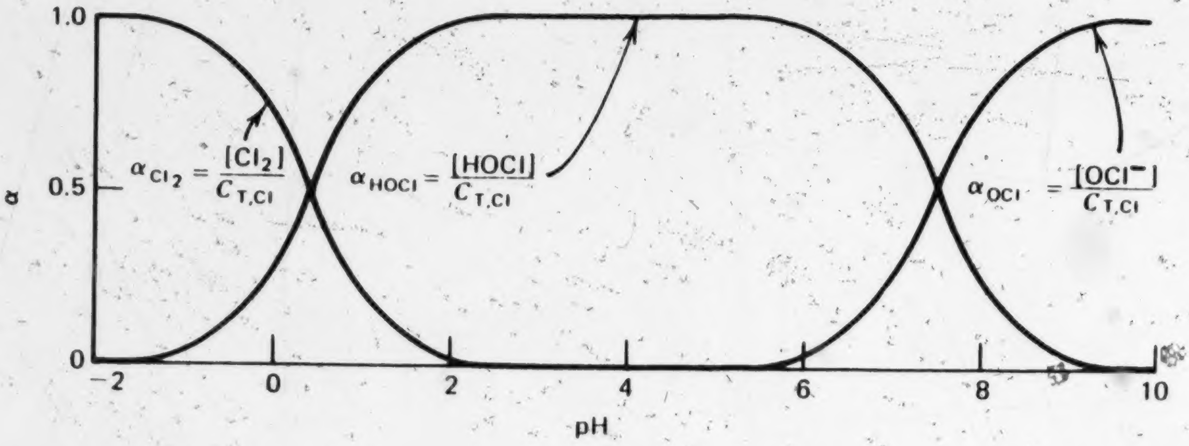


Figure 2.5 Distribution Diagram for Chlorine Species at 25°C. (Adapted from Soeyink and Jenkins 1980).

2.3.2 Reactions with Ammonia and Organic Nitrogen

Free available chlorine (FAC) reacts with ammonia and nitrogenous organic compounds (which may originate from bathers) to form inorganic and organic chloronitrogen containing compounds. These latter reactions are of particular importance in swimming pools (Gunkel et al. 1988, Jessen 1986, Lahl et al. 1981). The following reactions illustrate the different chloramine species that can be produced as part of the inorganic chloronitrogen compounds:

(2.3) $HOCl + NH_3 \rightarrow H_2O + NH_2Cl$ (monochloramine)

(2.4) $HOCl + NH_2Cl \rightarrow H_2O + NHCl_2$ (dichloramine)

(2.5) $HOCl + NHCl_2 \rightarrow H_2O + NCl_3$ (nitrogen trichloride)

These inorganic compounds are also identified as: chloramide (NH_2Cl), chlorimide ($NHCl_2$) and chlorine azide (NCl_3) (Shaw 1986). Nitrogen trichloride has also been called trichloramine. Production of chloramines proceeds very rapidly compared to the other chlorination reactions (Lietzke 1978), such as oxidation and substitution, but is not as fast as halogenation of organic nitrogenous compounds. In addition the kinetically dominated reactions are further enhanced by the thermodynamic aspect. In an effort to achieve equilibrium, chlorine from monochloramine transfers to N-organic compounds (Isaac and Morris 1980). As a result both the kinetic and thermodynamic aspect promote the formation of organic chloramines at the expense of inorganic chloramines, or other oxidation and substitution reactions. Chloramines and N-chloroorganic compound reactions are very dependent on pH, temperature, contact time, and on the initial ratio of chlorine to ammonia and/or N-organic compounds, especially amino compounds (White 1986 and Isaac and Morris 1980). The chlorine in both the inorganic and organic species with lower oxidation potential than FAC or slower reaction rate is called the "combined residual" chlorine (Jolley and Carpenter 1983). Chloramines also serve as disinfectants, although they are slower-reacting and provide lower disinfection efficiency (Metcalf & Eddy 1979, Lahl et al. 1981). The kinetic and thermodynamic preference towards the formation of N-chloroorganic compounds at the expense of chloramines interferes with disinfection because the N-chloroamino acids are essentially non-germicidal.

Chloramines have been proposed as being irritants and nitrogen trichloride produces noxious odours (Lahl et al. 1981, Metcalf & Eddy 1979). Their presence has also been given as an explanation for taste and odour problems in finished drinking water and in treated swimming pool water (Metcalf & Eddy 1979, Coopersmith 1990). Chloramine can be destroyed by breakpoint chlorination i.e. superchlorination of the pool water with high dosages of FAC.

2.3.3 Breakpoint Chlorination

The maintenance of a free available chlorine level is complicated because chlorine is an oxidant which is very reactive with many chemical compounds present in the pool water, including nitrogen containing species. The stepwise phenomenon of breakpoint chlorination is illustrated in Figure 2.6. The breakpoint curve illustrated is a function of different dosages applied measured at a given point in time and is the result of cumulative batch experiments. It does not correspond directly to changes occurring as a function of time.

Chlorine added to water will react with readily oxidizable substances, such as organic matter and inorganic ions, and be reduced to the chloride ion (point A in Figure 2.1). If sufficient chlorine is added to meet this immediate demand, the excess chlorine will react with the ammonia and N-organic containing compounds between points A and B. For experiments with mole ratios of chlorine to ammonia of less than 1, monochloramine and dichloramine are formed. The distribution of these two species is governed by their rates of formation, which in turn depend on the pH and temperature, as earlier mentioned. For experiments at dosages between point B and the breakpoint, some chloramines will be converted to nitrogen trichloride (see reaction 2.5) resulting in a noxious odour. The remaining chloramines are oxidized to nitrous oxide (N_2O) and nitrogen (N_2), and the chlorine is reduced to chloride ion (Cl^-). For dosages the breakpoint, most chloramines are oxidized. Reactions 2.6 to 2.9 describe the disappearance of chloramines and the formation of gases mentioned.

(2.6) $NH_2Cl + NHCl_2 \rightarrow N_2O + 4\,HCl$

(2.7) $4\,NH_2Cl + 3\,Cl_2 + H_2O \rightarrow N_2 + N_2O + 10\,HCl$

(2.8) $2\,NH_2Cl + HOCl \rightarrow N_2 + H_2O + 3\,HCl$

(2.9) $NH_2Cl + NHCl_2 \rightarrow N_2 + 3\,HCl$

Theoretically the mass ratio of chlorine (Cl_2) to ammonia nitrogen (NH_3-N) at the breakpoint is 7.6 : 1. The ratio will vary somewhat, depending on the actual reactions involved. Organic loading (e.g. load of bathers) will cause a greater immediate demand leading to a greater ratio. Continued addition of chlorine past the breakpoint, results in a directly proportional increase of FAC as indicated by the slope of 1 in Figure 2.1 (Metcalf & Eddy

1979, Jolley and Carpenter 1983). The main reason for adding enough chlorine to obtain a FAC residual is that disinfection becomes more reliable. The combined residual after breakpoint consists essentially of the organic chloramines not destroyed by free chlorine (Jolley and Carpenter 1983). The formation of additional products during chlorination will react with the alkalinity of the water. Under most circumstances only a small drop in pH occurs which can be controlled by the addition of sodium bicarbonate ($NaHCO_3$), soda ash ($NaCO_3$) or sodium hydroxide (NaOH).

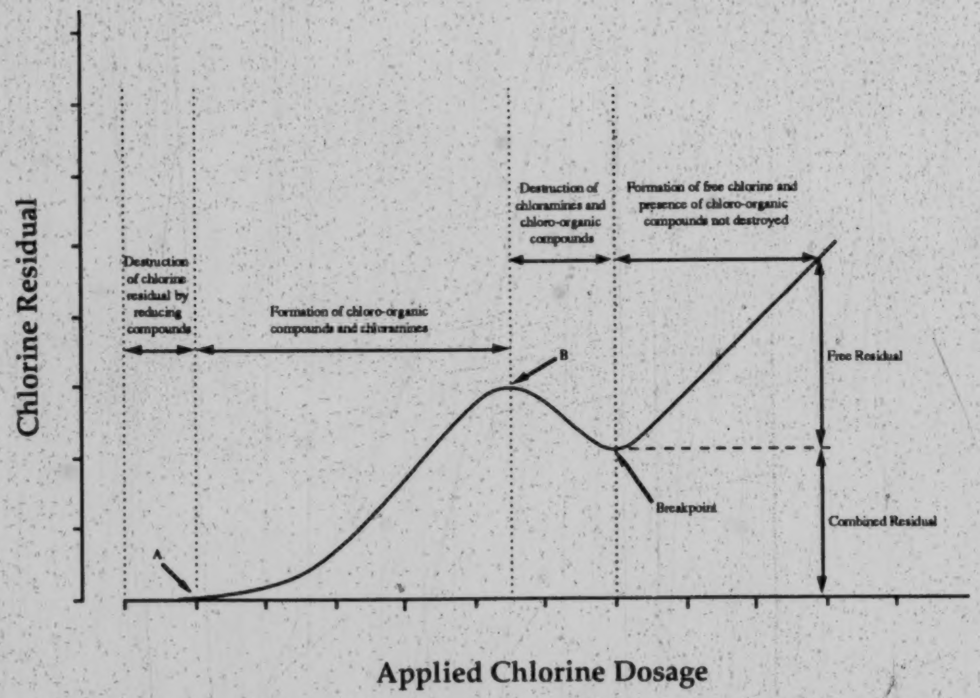


Figure 2.6 Generalized Curve Obtained During Breakpoint Chlorination. (Adapted from Metcalf & Eddy 1979 and Jolley and Carpenter 1983a)

2.4 Techniques Developed for Measurement of Airborne Contaminants

Over the last decade, indoor air quality has become a major concern. Consequently, a greater number of complaints have been investigated by different agencies (Bénard et al. 1990). With ~~indoor~~ swimming pool environments, the increased concern results from cases involving compensation costs for lost working days, injuries and in extreme cases, temporary closures of the facilities.

As mentioned earlier, indoor pool environments present particular atmospheric conditions that can create the potential for adverse health effects. From this perspective and the knowledge that complex aqueous chemical admixtures can potentially release volatile compounds and aerosols to the atmosphere, indoor air quality monitoring in swimming pools presents warrants investigation.

This study as limited its focus on monitoring aldehydes in the air phase because of their previously reported properties and also because of time constraint. Hrudey et al. (1989) have reported to have found aldehydes in the water phase of swimming pool and have suggested that the aldehydes would contribute to the characteristic "swimming pool" like odour. The perceived odour is best described by an organic swampy, sweaty odour.

An adequate air quality monitoring program is achieved through personal exposure monitoring (PEM) for the compound of interest with respect to a limiting criterion. A suitable limiting criterion is based on recommended exposure limits and knowledge of the adverse health effects resulting from exposure to the given compound. A monitoring detection limit (MDL) provides one criterion which is specific for each individual compound in regard to its properties. The monitoring procedure carries a practical quantification limit (PQL). If the PQL of a method of detection does not meet the MDL the method will not be suitable for PEM practice. Moreover, a PEM program must meet additional criteria to present commendable efficiency. A PEM should be simple, rugged, reliable, sensitive and specific to a suitable range of concentrations of the targeted compound (Otson and Fellin 1988). These latter criteria are based mainly on operation practicality.

No simple methods are available for the determination of all relevant targeted compounds. The techniques for measurements are divided into two categories: Direct Reading Methods and Indirect Methods. These latter methods include several derivatization approaches. The following review will be limited to methods applicable to airborne monitoring of aldehydes. Also an additional section will deal with the units most frequently used in the field of air quality monitoring, as well as explain the conversion between the different units.

2.4.1 Units in Air Monitoring

In reporting results for air phase monitoring units of ppm (parts per million), ppmv (parts per million volume) or μg/m^3 are most frequently used. The ppm units refer to a mass/mass ratio of 10^{-6} g/g, or mg/kg. When ppmv is used the ratio changes to a volume/volume of μL/L. The conversion between the two set of units can be performed by using the density of the air phase. Since the density changes with temperature change the values are conventionally reported for standard conditions (i.e. atmospheric pressure, 101.3 kPa and 20°C). The density for the air phase at 20°C is: 1.2 kg/m^3. The conversion is as follows:

Equation 2.3 $$\frac{\text{mg of contaminant}}{\text{kg of air}} = \text{ppm}$$

Equation 2.4 $$\frac{\mu\text{mole of contaminant}}{\text{mole of air}} = \text{ppmv}$$

Equation 2.5 $$\frac{\text{mg of contaminant}}{\text{kg of air}} \times 1.2\ \text{kg of air}/\text{m}^3 = \frac{\text{mg of contaminant}}{\text{m}^3\ \text{of air}}$$

$$\times \frac{1000\ \mu\text{g}}{\text{mg}} = \frac{\mu\text{g of contaminant}}{\text{m}^3\ \text{of air}}$$

2.4.2 Direct Reading Methods

Direct reading methods include a variety of instruments from the simplest detector tubes, i.e. Draeger tubes, to the more complex laser and infrared technology, i.e. long path-Fourier transform infrared spectroscopy (LP-FTIR). The direct reading methods make use of detection methods such as optical spectroscopy based on infrared (IR) and ultra-violet (UV) absorption principles. Other intricate, more specialized optical spectroscopy detection methods have also been used, i.e. piezoelectric crystal detectors, atmospheric pressure chemical ionization (APCI) and mass spectrometry (MS). Direct reading methods, also make use of specific chemical and electrochemical reactions as detection methods, i.e. the pararosaniline method and the electrochemical fuel detector used in the Lion formaldemeter. These methods are capable of detecting formaldehyde in the 1 to 10 ppm and 0.3 to 5 ppm range, respectively (Otson and Fellin 1988).

These methods, although they present the desirable qualities of spatial monitoring and immediate determination generally, do not provide sufficient sensitivity or are not fully developed. Adequately sensitive techniques (e.g. APCI) require unusual instrumentation highly trained personnel. For example 1 ppmv represents the maximum allowable exposure limits for formaldehyde in several jurisdictions, reinforcing the unsuitability of several of the direct reading methods for personal exposure monitoring. Further research is required to advance more suitable and reliable technology for many important indoor air contaminants.

2.4.3 Indirect Methods

Most of the methods used in the measurement of airborne contaminants are indirect methods and with the exception of direct injection of sample into an instrument (i.e. grab sample), the indirect methods require a concentration step of some kind. They usually represent an integrative sampling which can yield a time weighted average (TWA) exposure. The TWA can be obtained when using direct methods through calculation based on an average time exposure.

Indirect methods of measurement are sub-divided into active and passive sampling. Active sampling requires the use of a pump and has been most commonly used for area and personal exposure monitoring. However, the use of cumbersome equipment and need for equipment maintenance has encouraged development of passive sampling methods which are gaining in popularity. Passive methods are generally based on established active methods with adaptation of the sampling media and chemical analysis procedures. The main focus of this review will be those techniques which are currently being use for PEM and not those under research and development.

Indirect methods are further classified under two categories for convenience in reporting. Those requiring chromatographic analysis and, those utilizing other physical principles of detection, or non-chromatographic detection methods. The non-chromatographic analysis approaches can be summarized under the physical means of detection, namely: absorption spectrophotometric or colorimetric detection, titrimetric and polarographic detection. The techniques based on polarographic detection basically meet the same limits that the simpler colorimetric and titrimetric methods are achieving. The polarographic principle has not been widely applied, although it is somewhat promising. Testing of methods has been poorly documented and further development is required. The spectrophotometric, colorimetric and titrimetric detection methods are very closely related and are discussed further (Otson and Fellin 1988).

2.4.3.1 Non-Chromatographic Methods

Formaldehyde is ordinarily the major aldehyde component found in air. Formaldehyde is very water-soluble, while most higher molecular-weight aldehydes show decreasing solubility with increasing molecular weight. It is often desirable to use a method specific for formaldehyde and determine the other aldehydes present separately as a total response (Liptàk and Béla 1974). The most commonly used spectrophotometric or colorimetric adsorption methods for detection of formaldehyde in air is the chromotropic acid method (Otson and Fellin 1988 and Liptàk and Béla 1974). It is followed closely by the pararosaniline methods, but the latter is more prone to interference by other carbonyl compounds and other low-molecular weight aldehydes, such as acetaldehyde, acrolein and propionaldehyde. The 3-methyl-2-benzothiazolane hydrazone (MBTH) method is used for total aldehydes in air.

The colorimetric techniques offer either specificity for an aldehyde i.e. the chromotropic acid method or the ability to detect aldehydes as a general class of airborne contaminants, i.e. MBTH method. Unfortunately, detection limits for either the specific or general techniques, are significantly higher than the limiting criterion for suitable personal exposure monitoring (Otson and Fellin 1989).

Table 2.6 Non-Chromatographic Method of Analysis for Aldehydes. (Adapted from Liptàk 1974).

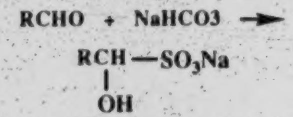
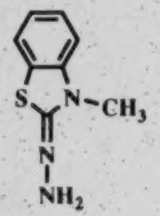
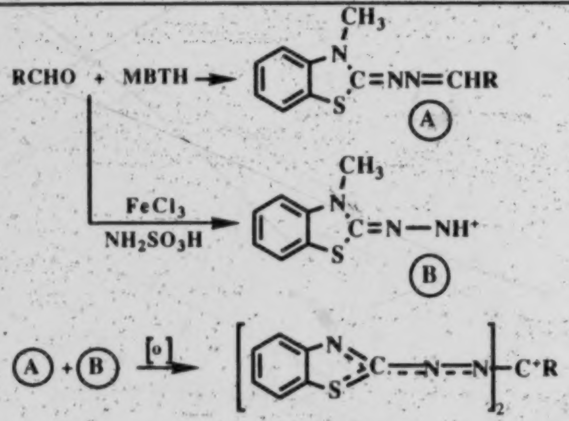
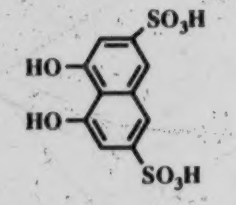
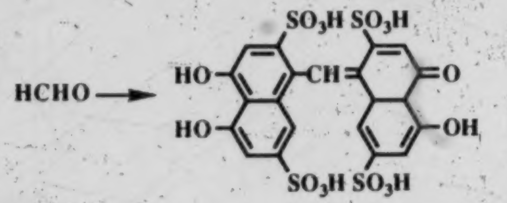
Reagent	Reaction Used	Method of Analysis	Limitations
Bisulfite (NaHSO3, aqueous)	 $RCHO + NaHCO3 \rightarrow \underset{\displaystyle OH}{\underset{\mid}{RCH}}-SO_3Na$	Destroy excess reagent add buffer determine HSO3 by iodometry	Lower molecular weight aldehydes only sensitivity moderate (useful for collecting for other methods)
Schiff's Reagent	Not well established	Colorimetric λ=560 nm	Responds more to formaldehyde than other aldehydes high purity dye essential
3-Methyl-2-benzothiazolone hydrazone (MBTH) 		Colorimetric λ=628 nm	Aliphatic aldehydes

Table 2.6 (Continued) Non-Chromatographic Method of Analysis for Aldehydes. (Adapted from Liptàk 1974).

Reagent	Reaction Used	Method of Analysis	Limitations
Chromotric acid 		Colorimetric λ=580 nm	Formaldehyde only: small negative interferences from phenols alcohols and certain olefins and aromatic hydrocarbons

2.4.3.2 Chromatographic Methods

Chromatographic methods have received wide spread attention and have normally been applied to airborne measurement of complex mixtures of aldehydes (Otson and Fellin 1988). These have utilized direct injection of sample into gas chromatographs (GC) or derivatization with subsequent analysis of the derivatives by high performance liquid chromatography (HPLC) or GC.

Derivatization procedures usually make use of an absorbent medium, onto which a reagent is impregnated, to trap the targeted compounds. In recent years, derivatization procedures have received wide spread attention for measurement of aldehydes in air. The advantages of in situ derivatization include stabilization of the aldehydes which reduce the requirements for complex storage procedures and allows time for transportation and analysis of samples. The increased molecular weight and acquired properties of the derivatives usually translate into enhanced sensitivity in regard to detectability. For example, one could cite the strong UV absorption of the 2,4-dinitrophenylhydrazine (DNPH) derivative for aldehydes or the nitrogen containing derivative resulting from reaction with N-benzylethanolamine (BEA), permitting detection with nitrogen-sensitive GC detectors. On the other hand, disadvantages of such methods are the labour intensive requirements for the extraction procedures involved and the many additional artifacts that can occur from such procedures.

The most widely used protocol for measurement of airborne aldehydes is the DNPH derivatization, employing collection and in-situ derivatization on an impinger coated with DNPH; completed by subsequent organic solvent extraction and, analysis by HPLC with UV detection or by GC. It is well adapted to chromatographic analysis which gives the lowest threshold values and separate analysis of each component (Carlier et al. 1986). The following reaction illustrates the process involved in the DNPH derivatization of aldehydes.

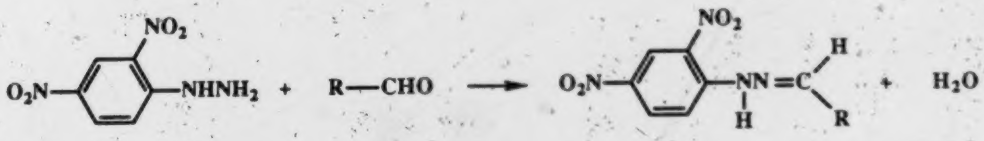


Figure 2.7 Generalized Reaction of the Derivatization of Aldehydes by the DNPH Method. (Adapted from Otson and Fellin 1988).

Note that when the group is H, formaldehyde is the component reacting and a single compound results. When the group is CH_3, acetaldehyde is the component reacting which results in the formation of Z and E isomers with the possibility of the molecule being flipped vertically at the plane of the double bound. This results in double peaks, one for each isomer formed and two different retention times. The resulting area counts of each individual peak for the isomer are added for the quantification analysis.

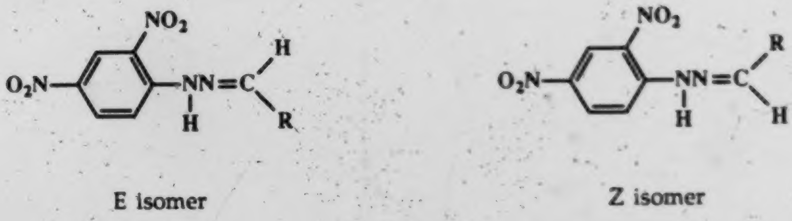


Figure 2.8 Configuration of the Isomers Formed in the Derivatization of Aldehydes by the DNPH Method.

2.5 Measurable Parameters Selected and Relevance for Study

2.5.1 Air Phase

In view of the explicit reports about the significance of air quality with respect to health effects, this project has studied certain chemical and microbial aspects of air quality. Aldehydes were chosen as chemical airborne contaminants for study because of their known irritant properties, their known occurrence in chlorine disinfected water and because they had not been previously studied in pools. In addition, a more general approach was used to determine traces of background chemical contaminants. Finally, microbial monitoring of the air phase was also performed.

2.5.1.1 Airborne Chemical Contaminants

Aldehydes were chosen as the parameters to be measured in the air phase because of its relative important levels in chlorinated swimming pool water found in previous research by Hrudey et al. (1989). Formaldehyde and acetaldehyde were found to be the two major aldehydes present in earlier water pool samples tested in this project. These findings were confirmed by previous work of Hrudey and Daignault (1989). The significant health effects from aldehyde exposure will increase the concern to be able to monitor their presence in the aerosol and the aqueous phase. Furthermore, aldehydes have been reported to contribute as odour causing agents in drinking water (Huck et al. 1990, Gac 1988, Hrudey et al. 1988, Hrudey et al 1989) as well as swimming pool water (Hrudey et al. 1989). The presence of odours indicate that causative chemicals have vaporized from the water phase.

Because the air phase aldehyde analysis is specific to the aldehydes a more general, non target analysis was also pursued to measure other gas phase components. For example, excess carbon dioxide was used as a marker for lack of adequate ventilation in previous research of air quality at indoor swimming pools (Bénard et al. 1990). FTIR analysis should permit detection of all the components of the air except the atoms and the symmetrical diatomic molecules. It is based on absorption of energy bands corresponding to rotation and vibration of the atoms composing a molecule. This latter method also allows a more general approach for detection of many airborne contaminants with levels in the part per million range. Unfortunately, this level of sensitivity is unlikely to be adequate for many of the trace contaminants present in a pool atmosphere.

2.5.1.2 Aerosol Monitoring

As indicated by Mangione et al. (1985), droplets greater than 2 microns potentially contain bacteria, and droplets less than 5 microns may be deposited in the pulmonary alveoli when inhaled. Subsequently, a knowledge of the microbial activity of the air phase gains importance as some of the symptoms reported are allergy-like symptoms and may in part be caused by aerosolized microorganisms in the swimming pool enclosure. There is also a possibility of less volatile chemicals being carried into the lungs via liquid aerosols.

2.5.2 Water Phase

2.5.2.1 Chlorine Speciation and Organic Loading

As described in the regulations and in previous disinfection sections, chlorine disinfection leads to many different, chemical species some of which have been reported as agents causing adverse health effects. Furthermore, free chlorine residuals and chlorine speciation is important to establish the quality of the disinfection process. As part of the long list of disinfection by-products in organically contaminated water sources, trihalomethanes, aldehydes, chloro-nitrogen containing compounds have been discussed and were chosen as part of the investigated parameters.

In addition, total organic carbon and total kjeldahl nitrogen measurements were included as well as large volume water sample extraction to acquire a better knowledge of the organic loading involved in swimming pools.

2.5.2.2 Pathogenic and Enteric Microorganisms

In this project, the microbial analyses were performed at the University of Alberta, Environmental Engineering and Science Laboratories and also at the Alberta Provincial Laboratories, Mycobacteriology Laboratory Division. The *Mycobacterium* assay was performed at the Provincial Laboratory because of the very high pathogenicity and the requirement for special containment.

The following list of microorganisms were analyzed by Karen M.E. Emde microbiologist at the University of Alberta Environmental Engineering and Science Laboratories: a) Presumptive *Klebsiella* species; b)*Pseudomonas aeruginosa; c) Mycobacterium* species; d) Total heterotrophic plate counts; e) Total and Faecal coliforms.

2.5.3 Physical Parameters of Interest

As part of the sampling program, pH, water temperature and conductivity measurements were also performed. In addition, relative humidity and ambient temperature readings for each day of sampling were obtained from the recorded data by swimming pool operators.

3. RESEARCH OBJECTIVES

3.1 Problem Overview

As mentioned earlier, the main objective of this project was to acquire a better understanding of the environmental factors at indoor public swimming pools which may affect human health. A companion part of this project dealt with a user interview survey to identify the frequency and character of health problems reported at indoor public swimming pools. The survey also provided a profile of the users in case of predisposition to health problems imposed by personal habits (e.g. smoking). Subsequently, explanation of the sources of these problems in correlation with the scientific data acquired about each site could be attempted. Finally, recommendations about suggested operational changes, to reduce the frequency of complaints, could be developed. For this purpose a step by step approach needs to be undertaken. These steps can be summarized by the following key points.

A questionnaire was administered by direct interviews to the facility users and the staff to establish the frequency and extent of health symptoms experienced. The questionnaire provided information about the interviewee and his/her swimming activity. A copy of the Health Survey of Public Pool Users Questionnaire is provided in Appendix A. Analysis of the results of this survey is being conducted separately from this thesis and these will be reported separately.

This thesis was directed towards providing the monitoring data which could be used, together with the questionnaire survey results and specific information about individual pools to judge the significance of health effects and the more promising directions for solving identified problems. The specific research objectives for the monitoring study consist of three components of data collection and validation at three selected, representative indoor pool facilities.

3.2 Specific Objectives

1. The first objective was to perform a comprehensive evaluation of many target chemical species. A variety of analyses were selected following the review of the literature. These were performed on different days (seasonal profile), different time of day (daily profile) and at different locations within same pools.

2. The second objectives was to perform an evaluation of targeted microbial species. Regular sampling was performed to accompany the chemical data gathered at each site. Indicator microorganisms, specified by the pool regulations, together with other suggested indicator organisms were studied.

3. The final objective was to perform an initial assessment for selected contaminants found in the water phase to determine their presence in the air phase. Possible air contaminants were identified by three different techniques. The first analysis dealt with potential emission of low molecular weight aldehydes from the water by volatilization. Aldehydes, especially formaldehyde, have received considerable attention as potential irritants. A second appraisal uses a sampling method with direct analysis by Fourier Transformed Infrared Determination to account for a broader, but less sensitive background chemical analysis of the air phase. Finally, an aerosol monitor was used to account for the possible transport of microorganisms in micro-droplets (aerosols) from the water to the air phase.

4. DESCRIPTION OF SWIMMING POOL FACILITIES STUDIED

Limited information about the size and type of facility at each site that was studied is presented. More detailed information about each facility can be found in the Appendix B.

4.1 Facility I

This facility offers multi-recreational disciplines housed in one building erected in 1978. The swimming pool area consists of four separate tanks ranging from a free style swimming pool to a wading pool. The first tank, identified as A on Figure 4.1, is a free style swimming pool of rectangular shape 50 m x 21 m with a depth of 2 to 2.3 m. The temperature of the water is kept at 26°C. The second tank is a rectangular diving unit of 25 m x 15.2 m with a depth of 4.9 m. The water temperature is kept at 28°C and the pool is identified as B on Figure 4.1. Three permanent diving boards are installed on one side, while up to five removable spring boards can be mounted on the opposite side and on the shorter sides of the pool. Usually, three spring boards are left on the shorter sides at all times. The third tank is also maintained at 28°C. It is rectangular with a uniform depth of 1 m. The pool is 51 m x 13 m and is separated in two equal parts by a 1 m mobile bulkhead. This pool was sampled as two individual tanks (identified as C and D on Figure 4.2) because the activities were different in each half. However, the bulkhead offers only an artificial separation, because it is submerged about 0.75 m leaving a space beneath for free circulation of water. The last tank, identified as pool E, is a wading pool presenting the warmest temperature at 36°C. It is rectangular with dimensions shape of 5 m x 13 m and a depth of 0.75 m.

Facility I purifies water using filtration and chlorination. The time required for a complete turnover of the pools are as follows: pool A about 5.5 h; pool B, C and D between 4 to 5 h and pool E about 50 min. Chlorine gas is used as disinfectant consuming 68 kg per week for all four pools. A minimum free available chlorine level of 2.0 ppm is aimed for. Addition of diatomaceous earth is performed every 7 to 10 days.

An engineering study of the ventilation system was completed in 1988 following repeated complaints of patrons and operational staffs. As a result of the study, the following corrective measures were implemented: 1) filters were changed from fibreglass material to synthetic material in May 1990, 2) a dehumidification system was installed during the months of July to September 1990.

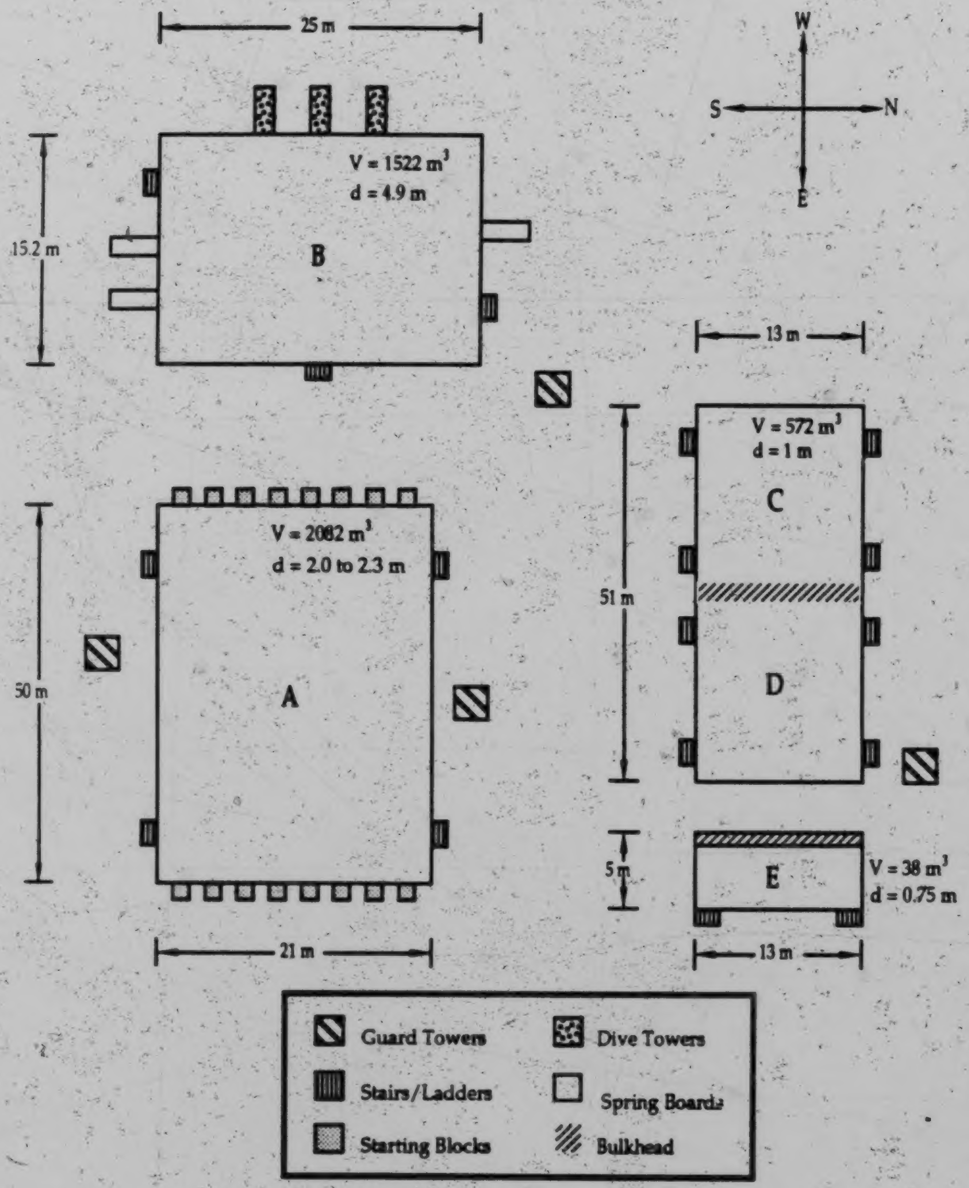

W
S
N
E
25 m
15.2 m
V = 1522 m^3
d = 4.9 m
B
13 m
V = 572 m^3
d = 1 m
C
51 m
D
50 m
V = 2082 m^3
d = 2.0 to 2.3 m
A
5 m
E
V = 38 m^3
d = 0.75 m
21 m
13 m
Guard Towers
Dive Towers
Stairs/Ladders
Spring Boards
Starting Blocks
Bulkhead

Figure 4.1 Schematic of Facility I with Identification of the Different Swimming Pool Dimensions.

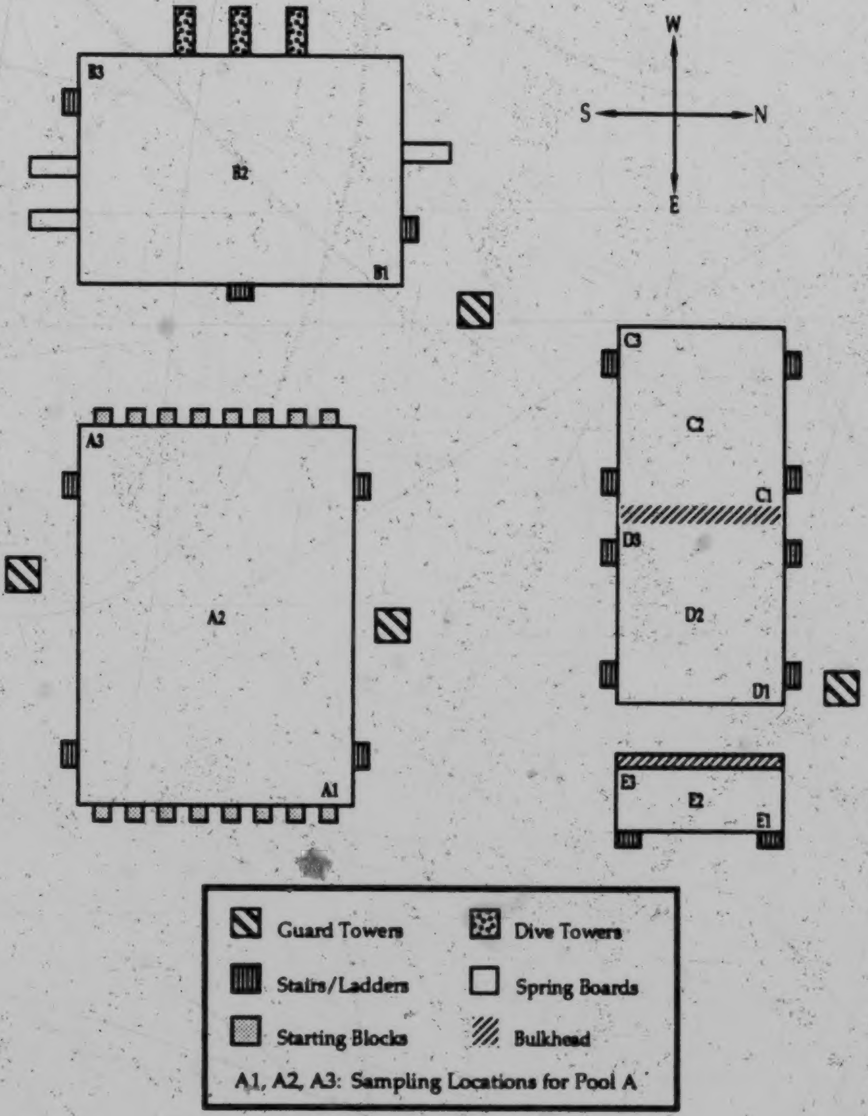

W
S
N
E
B3
B2
B1
A3
A2
A1
C3
C2
C1
D3
D2
D1
E3
E2
E1
Guard Towers
Dive Towers
Stairs/Ladders
Spring Boards
Starting Blocks
Bulkhead
A1, A2, A3: Sampling Locations for Pool A

Figure 4.2 Schematic of Facility I with Identification of the Different Aqueous Sampling Locations for Pools A to E.

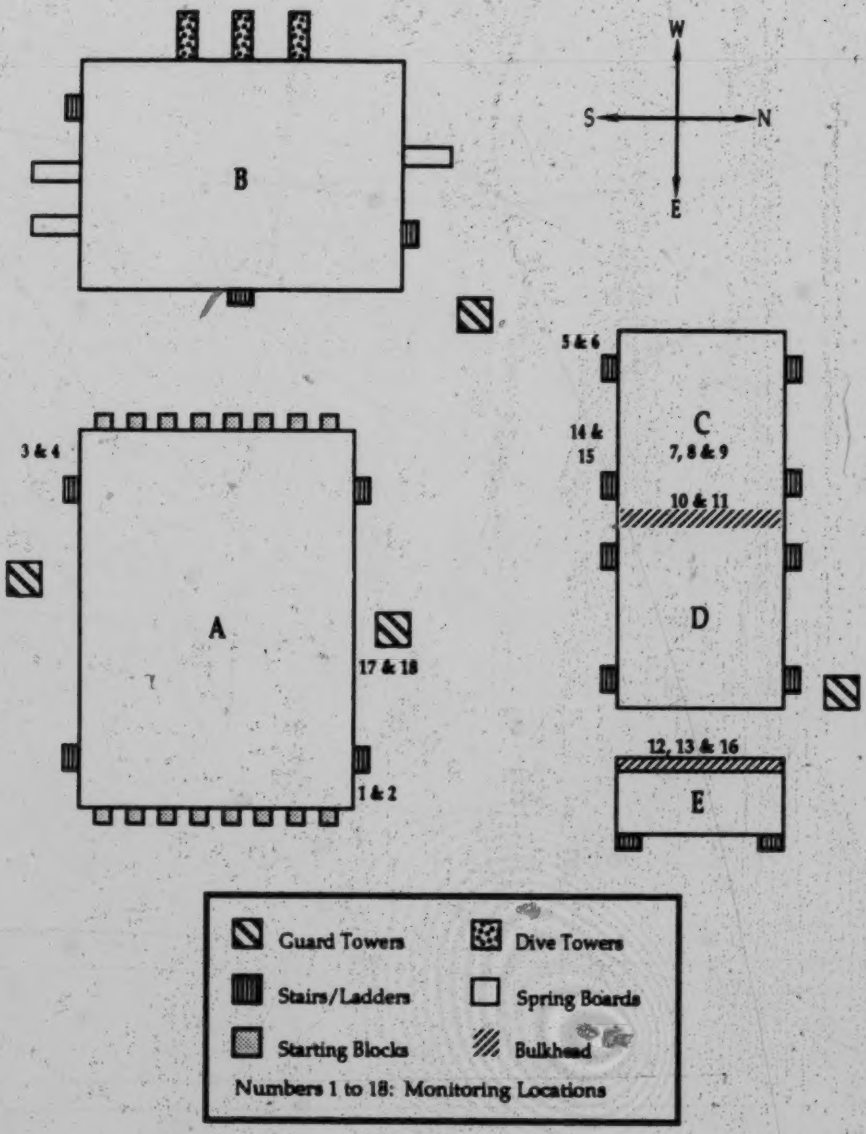

W
S
N
E
B
A
C
D
E
3 & 4
5 & 6
14 & 15
7, 8 & 9
10 & 11
17 & 18
1 & 2
12, 13 & 16
Guard Towers
Dive Towers
Stairs/Ladders
Spring Boards
Starting Blocks
Bulkhead
Numbers 1 to 18: Monitoring Locations

Figure 4.3 Schematic of Facility I with Identification of the Different Aerosol Monitoring Locations.

4.2 Facility II

This facility offers multi-recreational disciplines housed in the same building. The site was opened to public in 1982. The swimming pool area has four tanks and is classified as a "water theme park". This includes a wave pool, diving tank, hot tubs, slides, water flumes and steam showers. The diving tank is of rectangular shape with dimensions of 12.8 m x 8.2 m and a depth of 3.7 m. It is identified as pool α in Figures 4.4 and 4.5. The wave pool is of irregular shape. The dimensions are as illustrated on the schematic in Figures 4.4 and 4.5 with the pool labelled as β. The last two pools are circular with diameters of 3.0 m with a maximum depth of 1.5 m. They are identified by χ and δ in Figures 4.4 and 4.5.

The water park provides water treatment with filtration and chlorination. Chlorine gas is used for pools α and β, and 12% sodium hypochlorite solution is used for the hot tubs, pools χ and δ. Chemical addition is performed by metered pumps under computerized control, Strantrol Model 311B system, and additional manual testing is performed four times daily. A free available chlorine residual of 2.0 ppm is aimed for.

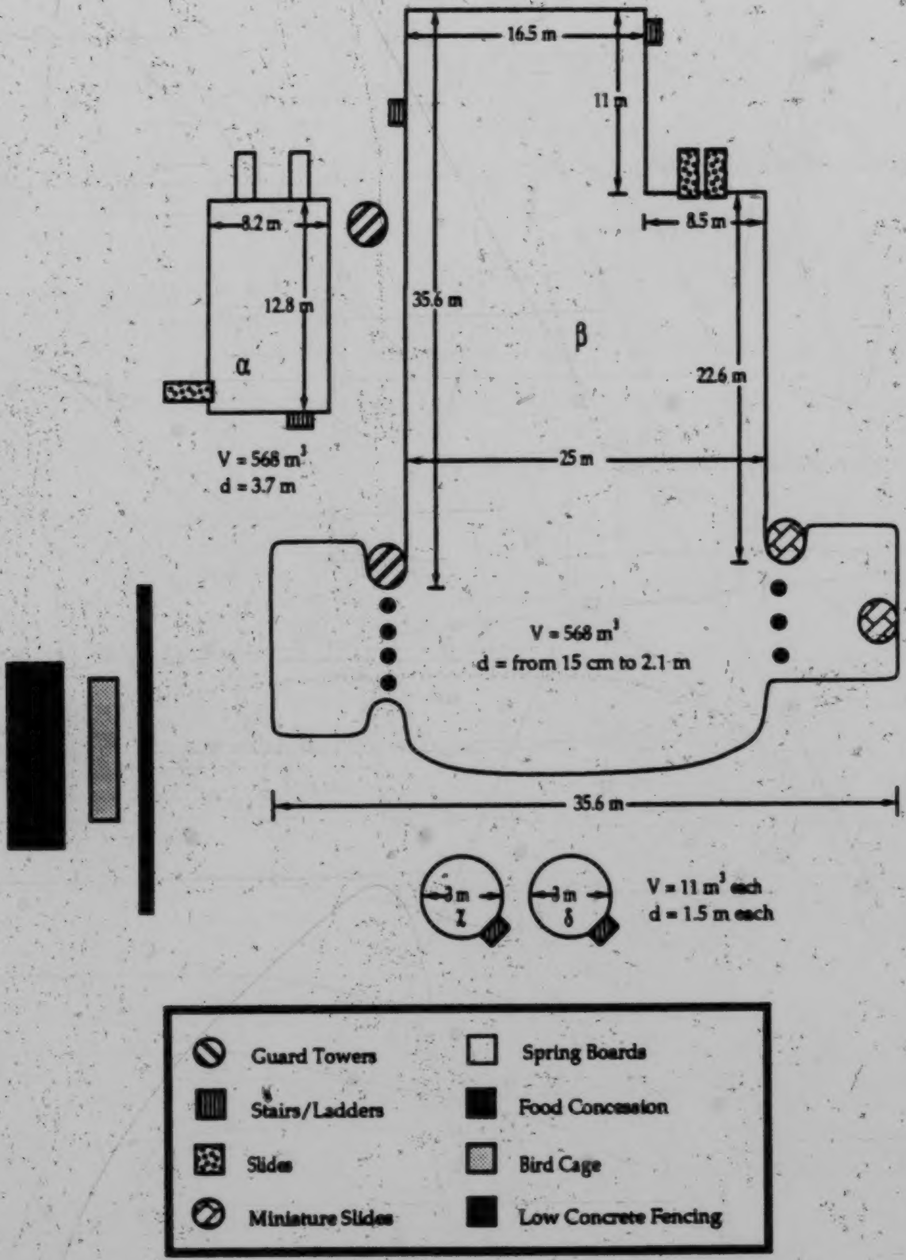

16.5 m
11 m
8.2 m
12.8 m
α
V = 568 m³
d = 3.7 m
35.6 m
β
8.5 m
22.6 m
25 m
V = 568 m³
d = from 15 cm to 2.1 m
35.6 m
3 m
γ
3 m
δ
V = 11 m³ each
d = 1.5 m each
Guard Towers
Stairs/Ladders
Slides
Miniature Slides
Spring Boards
Food Concession
Bird Cage
Low Concrete Fencing

Figure 4.4 Schematic of Facility II with Identification of the Different Swimming Pool Dimensions.

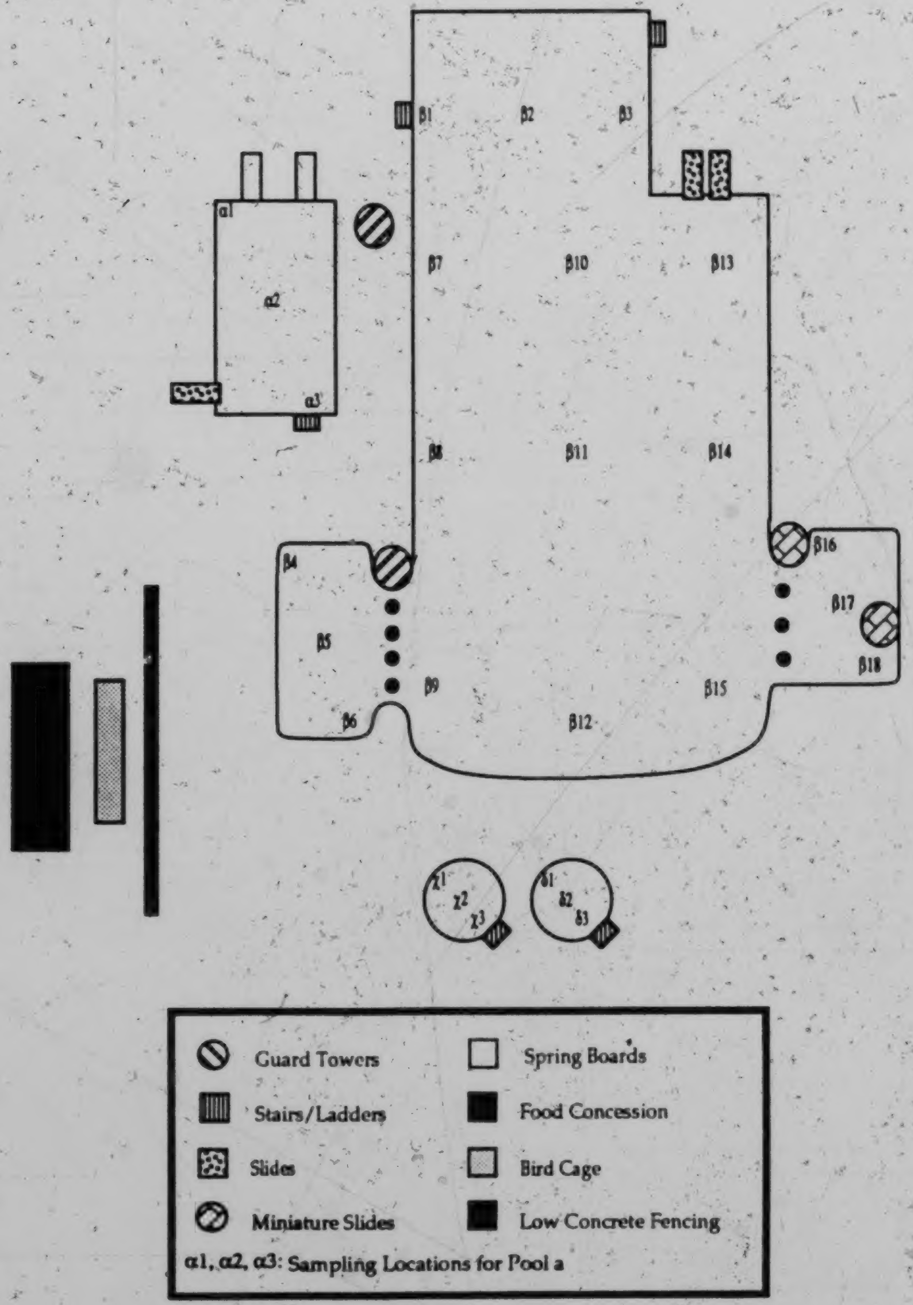

β1
β2
β3
α1
α2
α3
β7
β10
β13
β8
β11
β14
β4
β5
β6
β9
β12
β15
β16
β17
β18
γ1
γ2
γ3
δ1
δ2
δ3
Guard Towers
Spring Boards
Stairs/Ladders
Food Concession
Slides
Bird Cage
Miniature Slides
Low Concrete Fencing
α1, α2, α3: Sampling Locations for Pool a

Figure 4.5 Schematic of Facility II with Identification of the Different Swimming Pool Aqueous Sampling Locations.

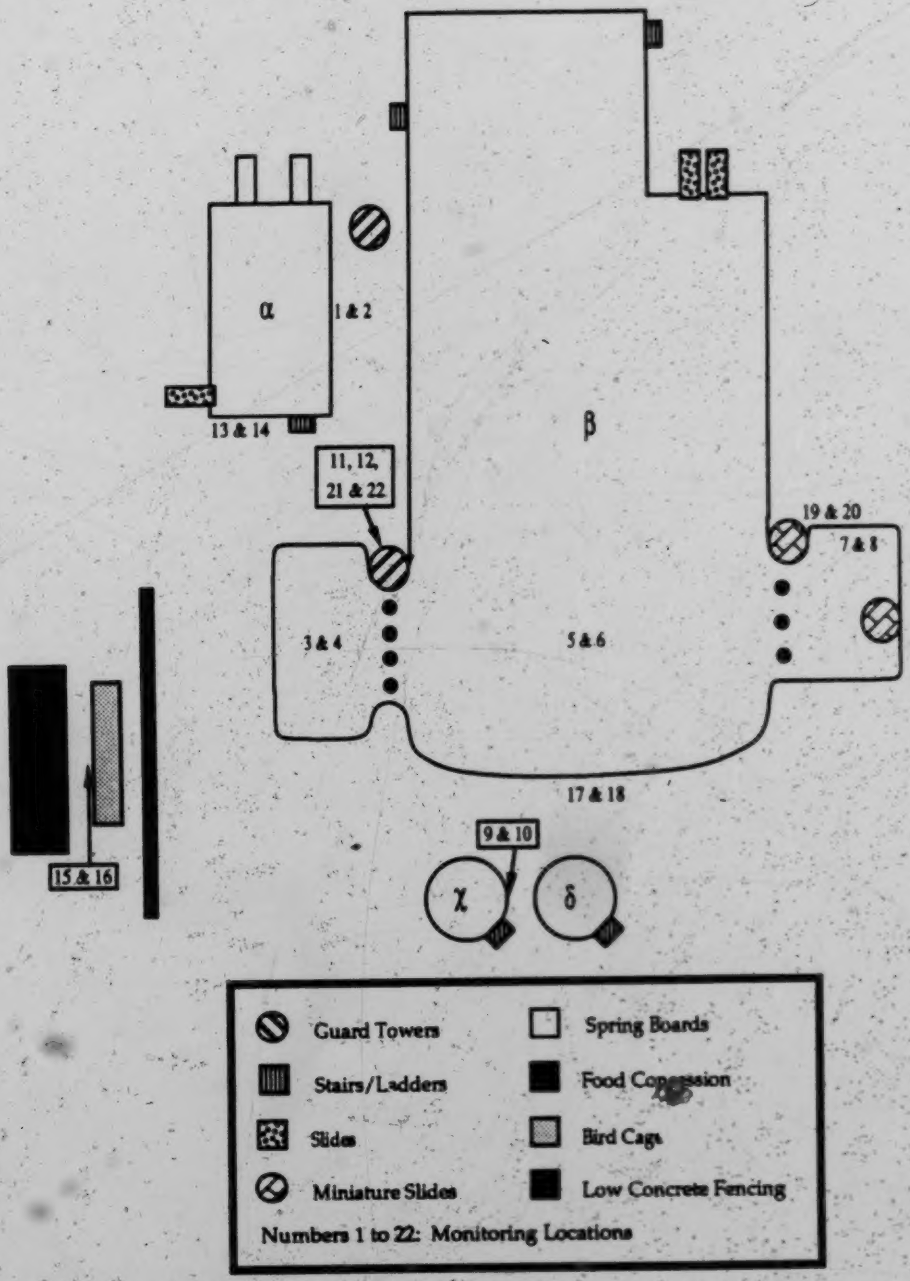

α
1 & 2
13 & 14
11, 12, 21 & 22
β
19 & 20
7 & 8
3 & 4
5 & 6
17 & 18
9 & 10
15 & 16
χ
δ
Guard Towers
Spring Boards
Stairs/Ladders
Food Concession
Slides
Bird Cage
Miniature Slides
Low Concrete Fencing
Numbers 1 to 22: Monitoring Locations

Figure 4.6 Schematic of Facility II with Identification of the Different Aerosol Monitoring Locations.

4.3 Facility III

The third facility is a single swimming pool housed in a semi-detached building which is part of a complex housing other types of activities, including sports activities. The swimming pool area was opened to the public in 1985. The pool has a rectangular shape of 52 m x 21 m with an uneven depth along its length ranging from 2.4 m to 4.5 m. The tank can be divided into three portions by two, 1 m, mobile bulkheads. The shallow end has the added feature of providing changeable depth with a mobile bottom mounted on hydraulic pumps. The pool dimensions are as illustrated in the schematic of Figure 4.7.

The facility treats the water using filtration and chlorination. Chlorine gas is used as disinfectant consuming 68 kg for 15 days of operation. Chemical addition is performed by metered pumps under computerized control, Strantrol Model 390 system, and additional manual testing is performed twice daily (at noon and at 4h30). A free available chlorine residual of 1.5 ppm is aimed for.

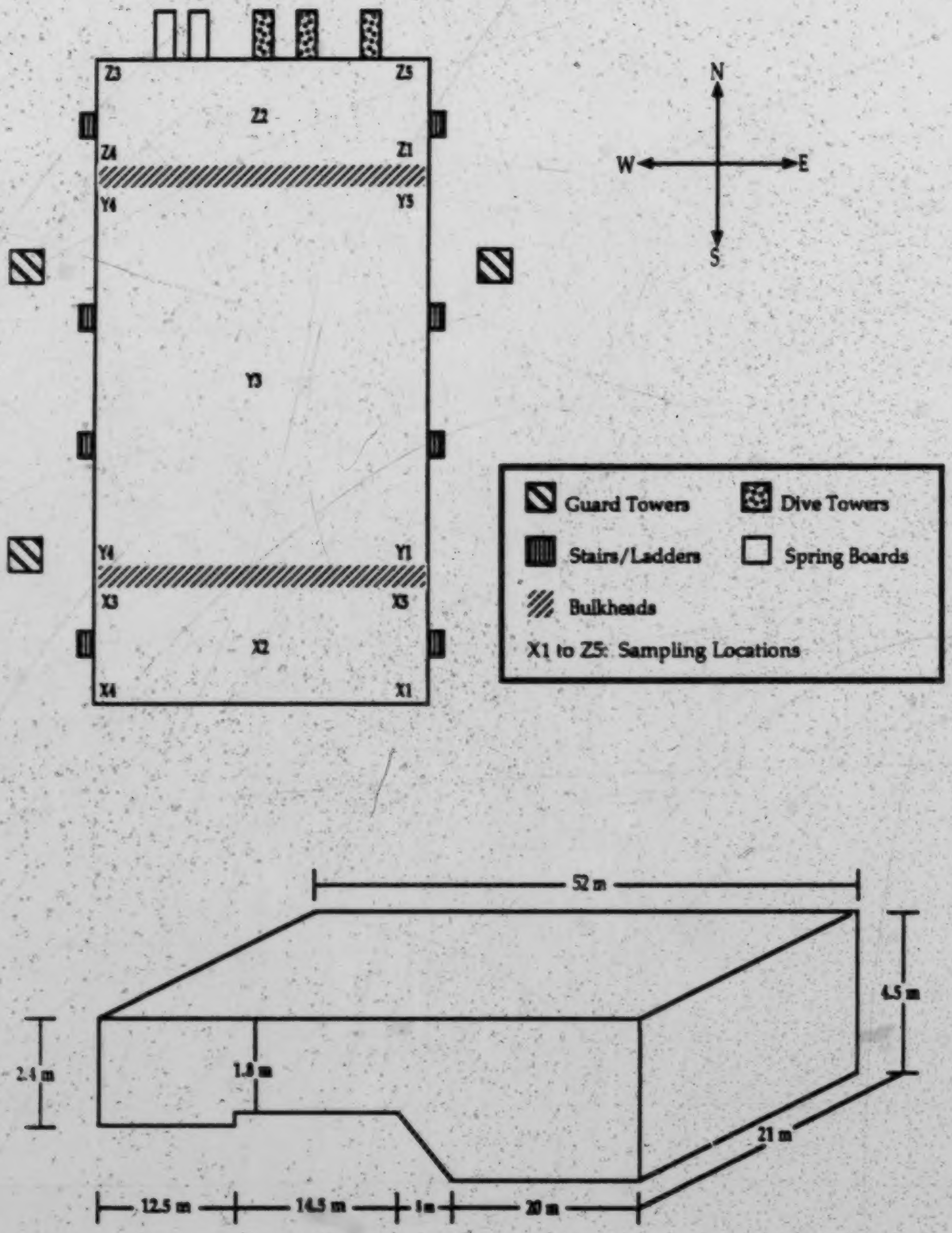

Z3
Z5
Z2
Z4
Z1
Y4
Y5
Y3
Y4
Y1
X3
X5
X2
X4
X1
N
W
E
S
Guard Towers
Dive Towers
Stairs/Ladders
Spring Boards
Bulkheads
X1 to Z5: Sampling Locations
52 m
4.5 m
2.4 m
1.8 m
21 m
12.5 m
14.5 m
1 m
20 m

Figure 4.7 Schematic of Facility III with Identification of the Swimming Pool Dimensions and Aqueous Sampling Locations.

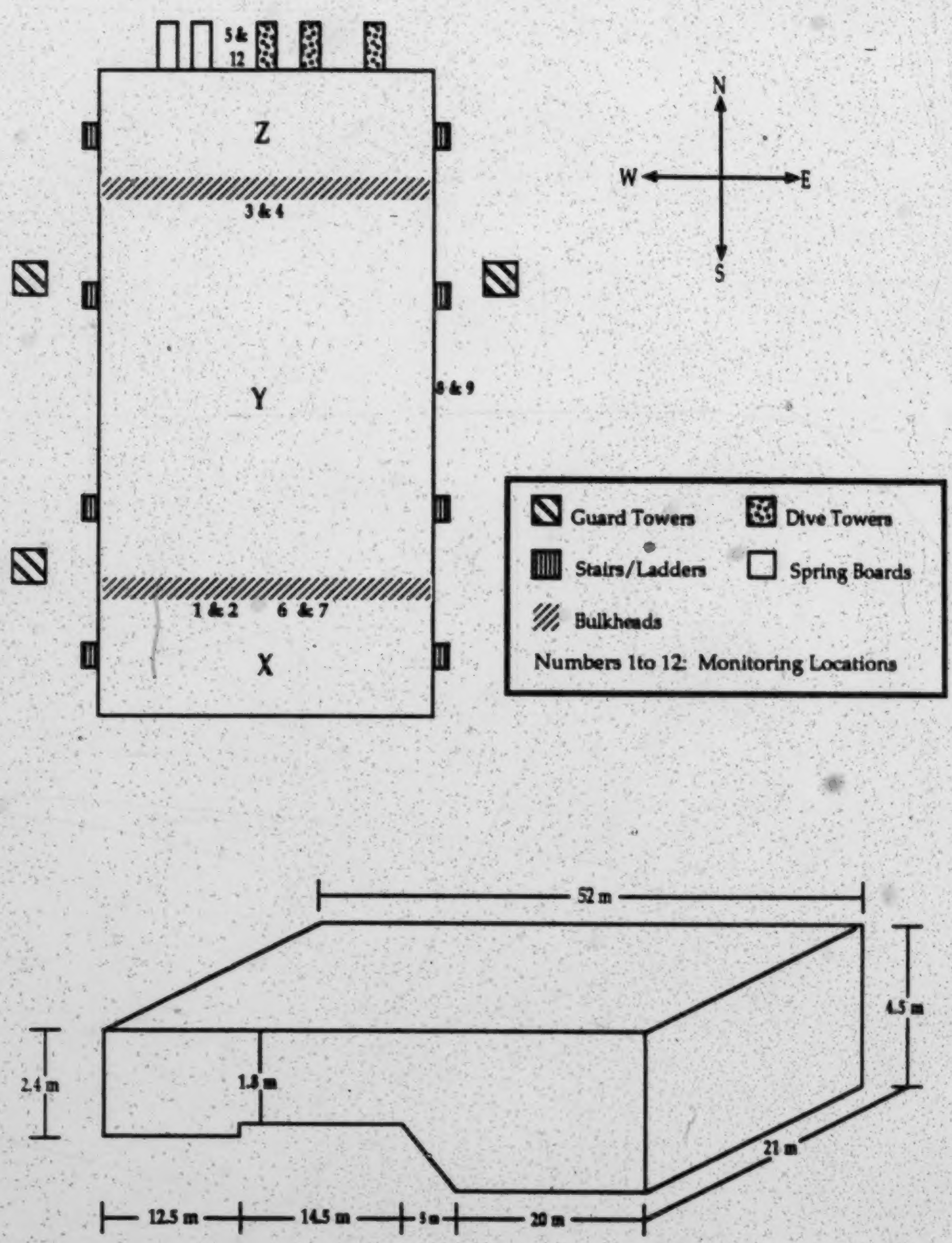

5 &
12
Z
3 & 4
Y
8 & 9
1 & 2
6 & 7
X
N
W
E
S
Guard Towers
Dive Towers
Stairs/Ladders
Spring Boards
Bulkheads
Numbers 1to 12: Monitoring Locations
52 m
4.5 m
2.4 m
1.8 m
21 m
12.5 m
14.5 m
5 m
20 m

Figure 4.8 Schematic of Facility III with Identification of the Different Aerosol Monitoring Locations.

5. EXPERIMENTAL METHODS AND PROCEDURES

5.1 Chemical Analysis of the Water Phase

5.1.1 Aldehydes

Samples for the aldehyde analyses were collected in 40 mL Fisher brand glass vials capped with black phenolic resin screw cap containing a Teflon®-lined, silicone septum. The vials were immersed and sealed underwater when sampling. The samples were later treated with a 0.1 M sodium thiosulfate solution to quench chlorine recapped (head-space free), and stored at 4°C in the dark until analyzed. The dechlorination of the samples took place at the site of sampling, if delay of more than one hour was projected for travelling purposes. When the delay was under one hour, the samples were dechlorinated upon arrival at the University of Alberta. Samples were kept in ice-cooled coolers for travelling purposes.

Aldehydes were analyzed by the PFBOA (O-(2,3,4,5,6-pentafluorobenzylhydroxylamine) aqueous derivatization method reported by Glaze et al. (1989), with the following modifications. 20 mL of the pre-dechlorinated sample was transferred (or 20 mL of the aqueous standard solution and eight drops of 0.1 M sodium thiosulfate solution) into a clean 40 mL screw-cap sampling vials (described in the sampling procedure), and 2 mL of 1 mg/mL of PFBOA reagent prepared in Milli-Q® water was added. The solution was mixed by shaking and the reaction allowed to proceed at room temperature for 2 h. Subsequently four drops of 18 N sulfuric acid were added to each vial, the vial were shaken for 30 seconds and the derivatives were extracted with 5 mL of hexane containing 1,3-dibromopropane (DBP) as internal standard. The hexane-extracting solvent containing DBP was prepared by adding 500 μL of a stock solution composed of 5 μL of neat DBP in 25 mL of hexane, and was stored at 4°C in the dark in a sealed glass container with a Teflon®-lined screw cap between uses. The organic layer was transferred to a second 40 mL screw-cap sampling vial and was acid washed with 5 mL of 0.1 N sulfuric acid solution to minimize excess PFBOA reagent interferences. The hexane extract was removed and dried over anhydrous sodium sulfate in a 1 dram screw-cap vial with Teflon®-lined rubber septum and stored at 4°C in the dark prior to analysis.

Aldehyde derivatives were analyzed by using a Hewlett Packard (HP) 5790A gas chromatograph (GC) equipped with an electron capture detector (ECD) and a 30 m x 0.26 mm x 0.25 µm methylsilicone capillary column (DB-1). The injector and detector temperature were 220°C and 300°C, respectively. The GC oven temperature program was operated as follows: hold for 5 min at 100°C; increase by 10°C/min; hold for 0.8 min at 290°C. The final hold time was eventually prolonged to 5 min to ensure a longer bake out at the end of each GC run. Aldehydes were identified by relative retention time and quantified using standard curves of aldehyde and internal standard peak area ratios. Stock aldehyde standard solutions for standards were prepared by measuring appropriate microlitre volumes of the neat liquid aldehyde into Milli-Q® water. Serial dilutions of these solutions produced standard solutions of desired concentrations. Acetaldehyde was measured by weight instead of volume because of its high volatility and difficulty to measure by Hamilton syringe. Formaldehyde solution was standardized by NIOSH Method 3501 before use. Appendix D.1 contains results for the formaldehyde standardization and aldehyde standard curves.

5.1.2 Chlorine Speciation

Samples for the chlorine speciation analyses were collected in 500 mL amber glass bottles capped with black phenolic resin closures with polyvinyl disk type liners padded with Teflon®-liners. The bottles were immersed and sealed underwater when sampling. The samples were stored at 4°C in the dark until analyzed. 500 mL clear glass Wheaton "400" Brand bottles with screw-cap covered with aluminium foil also had to be used for sample collection. Samples were kept in ice cooled coolers for travelling purposes.

Chlorine speciation analyses were performed following Standards Methods for the Examination of Water and Waste Water Method (APHA et al. 1989) 4500-Cl F (DPD Ferrous Titrimetric Method). Standardization of the ferrous ammonium sulfate (FAS) titrant was performed by combining Method 4500-Cl B., sections 2, 3 and 4 and, Method 4500-Cl C., section 3. This had to be performed to make up for the lack of one chemical serving has indicator, barium diphenylamine, in the usual Method 4500-Cl F., section 2. Details concerning the standardization of the FAS procedure and the sample results can be found in Appendix D.2.

5.1.3 Trihalomethanes

5.1.3.1 Trihalomethane Standards

Trihalomethanes standard mixture 601-M1, containing 0.2 mg/mL each of chloroform, bromodichloromethane, dibromochloromethane and bromoform in methanol was obtained from Supelco Canada (Oakville, Ontario). This was the stock standard used in all trihalomethane analyses for quality control and the standard upon which calibrations were performed.

5.1.3.2 Trihalomethane Analyses

Samples for the trihalomethane analyses were collected in 40 mL Fisher brand glass vial capped with black phenolic screw cap with Teflon®-lined silicone septum. The vials were immersed and sealed underwater when sampling. The samples were later treated with a 0.1 M sodium thiosulfate solution, recapped (head-space free), and stored at 4°C in the dark until analyzed. The dechlorination of the samples took place at the site of sampling, if a delay of more than one hour was projected for travelling purposes. When the delay was under one hour, the samples were dechlorinated upon arrival at the University of Alberta. Samples were kept in ice cooled coolers for travelling purposes.

The four components were analyzed according to EPA method 501.1. A Varian gas chromatograph model 3300 equipped with a flame ionization detector (FID) and a 3 m x 0.25 cm packed column with 1% SP1000 on Carbopack B (60/80 mesh) was used in conjunction with a Tekmar liquid sample concentrator (LSC-2) interfaced with an automatic laboratory sampler (ALS) and a Spectra-Physics model SP4290 integrator. Details concerning specific instrument operating parameters, calibration, and quality control procedure are presented in Appendix D.3.

5.1.4 Total Kjeldahl Nitrogen

Samples for the total kjeldahl nitrogen analyses were collected in 500 mL clear glass Wheaton "400" Brand bottles with Teflon®-lined screw-cap. The vials were immersed and sealed underwater when sampling. The samples were later treated with a 3.5 g/L sodium thiosulfate solution, recapped (head-space free), and stored at 4°C in the dark until analyzed. The dechlorination of the samples took place at the site of sampling, if delay of more than one hour was projected for travelling purposes. When the delay was under one hour, the samples were dechlorinated upon arrival at the University of Alberta. Samples were kept in ice cooled coolers for travelling purposes.

Total kjeldahl nitrogen analyses were performed following Standards Methods for the Examination of Water and Waste Water Method 4500-N_{org} B. (Macro-Kjeldahl Method). Standardization of the sulfuric acid titrant was performed as per Method 2320 B. Details concerning the standardization of the sulfuric acid procedure can be found in Appendix D.4.

5.1.5 Total Organic Carbon

Samples for the total organic carbon analyses were collected in 237 mL Qorpak glass bottles capped with green phenolic resin closures. The closures are padded with a Teflon®-lined polyethylene film/foam extrusion. The bottles were immersed and sealed underwater when sampling. The samples were later acidified with sulfuric acid at pH=2, recapped (head-space free), and stored at 4°C in the dark until analyzed. The acidification of the samples took place at the site of sampling, if delay of more than one hour was projected for travelling purposes. When the delay was under one hour, the samples were acidified upon arrival at the University of Alberta.

Analyses were performed with a Dorhmann-Xertex DC 80 Total Carbon Analyzer utilizing UV promoted potassium persulfate oxidation followed by IR detection of the resulting carbon dioxide. The system is completed by an ASM-1 auto-sampler and provides 190 seconds of purging for every sample contained in a Pyrex culture tube (18 x 150 mm).

The following quality control program was used: fresh 10 ppm C standard solution was prepared for each day of analysis from a stock standard solution of 2000 ppm. This latter stock solution can be kept in the refrigerator for up to one month. Prior to preparation, the standard potassium hydrogen-phthalate (KHP), for total carbon analyses, was dried at 103°C overnight and kept in a desiccator. It was not found necessary to dry the KHP at a later time.

during the project, since it was kept in a sealed desiccator and remained moisture free as proven by the response of the apparatus. The inorganic calibration can be performed from sodium bicarbonate which was dried in a similar fashion as KHP. In our case, the inorganic carbon content in the acidified, purged sample was very small, so the calibration was not really necessary. Instead the UV lamp was turned off and time was allowed for the baseline to become stable. Then the inorganic carbon analyses were performed (with the lamp off). The same sequence of tubes was used if there was enough sample remaining in them or if necessary the tubes were refilled. Calibration in the TC mode was performed before every analysis run and a standard was checked again during the actual run to insure that baseline did not deviate.

It was found during the sequence of experimentation that the initial two inner positions on the ASM-1 autosampler do not receive as much purging time as the others; this problem is inherent to the system and cannot be modified in any way. It was convenient to simply use those initial inner position with deionized water to avoid the problem.

5.1.6 Large Volume Aqueous Sample Extraction

Large volume aqueous sample extraction and subsequent analysis by GC-mass selective detector (MSD) were performed by Norine Motkosky, environmental chemist at the University of Alberta, Environmental Engineering and Science Laboratories.

Samples for the large water sample extraction were collected in a Nalgene® 30 L polyethylene carboy. No special treatment was performed on the sample. The sample was transported without any refrigeration (note that the experiment was performed only during the November and December sampling activities and that outside temperatures were not warm).

The following analysis protocol was observed. 1.5 L of water was placed in a solvent cleaned 2 L separatory funnel. The pH of the water was adjusted to greater than 10 by addition of 50% w/w sodium hydroxide solution. The water was then extracted by shaking for 2 minutes with 60 mL of doubly distilled methylene chloride. The organic layer was allowed to separate and was drained out of the separatory funnel through clean anhydrous sodium sulfate. The water was extracted with 2 additional portions of 60 mL of methylene chloride, each time drying the organic layer through anhydrous sodium sulfate. The pH of the 1.5 L of water was then adjusted to less than 2 by addition of concentrated sulfuric acid. The water was then extracted with 3 portions of 60 mL of doubly distilled methylene chloride as described above.

The basic extracts from a total of 21 L of pool water were combined and the volume reduced in a Kuderna-Danish apparatus with Schneider column. The final volume of concentrated extract was 1 mL. The acid extracts from 21 L of pool water were combined and the volume reduced to 1 mL as described for the basic extracts.

The acid and basic concentrated extracts were analyzed by using a Hewlett Packard 5890 Series II gas chromatograph equipped with a Hewlett Packard 5970 mass selective detector and using a 30 m x 0.26 mm x 0.25 µm methylsilicone capillary column (DB-1). The injector and detector temperature were 225°C and 250°C, respectively. The GC oven temperature program was as follow: hold for 5 min at 35°C; increase by 5°C/min; hold for 5 min at 290°C.

5.2 Chemical Analysis of the Air Phase

5.2.1 Adsorption Tube Sampling

The method employed for the sampling of trace amounts of aldehydes in the air phase is an indirect active method of sampling. The general idea is to make use of an adsorbent surface (silica gel) onto which the derivatization reagent (2,4-dinitrophenylhydrazine) has been impregnated and packed in a sampling device (glass tube). The air sample is introduced in contact with the reagent with the use of a pump. The pump is set at a known flow rate. The following procedure will describe the preliminary preparatives, sampling tube packing and recovery of the resulting derivatized aldehydes, known as hydrazones.

5.2.1.1 2,4-Dinitrophenylhydrazine Recrystallization

In a first step, 2,4-dinitrophenylhydrazine (DNPH), obtained from Aldrich (Milwaukee, Wisconsin), was recrystallized from water following Aoyama and Yashiro (1983). Although other authors have used different recrystallization solvents such as carbonyl free ethanol (Johnson et al. 1981); HPLC grade acetonitrile (Tejaba 1986); 4 M hydrochloric acid (Rietz 1985) and extraction with 70:30 hexane:methylene chloride (Grosjean 1983, Fung and Grosjean 1981), recrystallization with Milli-Q® water was used because of a large amount of solvent were required and, the multiple artifacts which could occur from trace amounts of aldehydes accompanying the other solvents. Hydrochloric acid is used as a catalytic agent in the reaction of derivatization with DNPH to yield hydrazone. There is no advantage in using an acidified solution in recrystallizing DNPH since trace amounts of aldehydes would be encouraged to react and precipitate with the DNPH (Beasley et al. 1980).

5.2.1.2 Standard Hydrazones Synthesis and Analysis

Following recrystallization of the DNPH, pure hydrazone was synthesized following the method described by Schriner et al. (1964), except for slight modifications described hereafter. Heating of the recrystallized hydrazone was performed over a heating mantle in a round bottom flask, instead of over a steam cone in an Erlenmeyer flask. If sufficient 95% ethanol is used (in order to avoid supersaturation and poor recrystallization conditions) it is not necessary to perform filtration over a fluted filter prior to crystallization, instead a vacuum filtration apparatus can be used after completion of the recrystallization. Also, after leaving the filtrate in the refrigerator overnight, instead of 12 h at room temperature, secondary recrystallization from the filtrate was found to be negligible.

Hydrazone standards for gas chromatographic analysis were prepared by weighing a known amount of pure hydrazone into a 50 mL volumetric flask and diluting to volume with doubly distilled ethyl acetate. Subsequent dilution of this stock solution was performed to prepare calibration curves. Anthracene was added as an internal standard. Aldehyde derivatives were analyzed by using a HP 5890 gas chromatograph equipped with a flame ionization detector (FID) and a 30 m x 0.26 mm x 0.25 µm methylsilicone capillary column (DB-1). The injector and detector temperatures were 250°C and 300°C, respectively. The GC oven temperature program was operated as follows: hold for 5 min at 100°C; increase by 10°C/min; hold for 5 min at 290°C.

5.2.1.3 Coating of Silica Gel with Reagent

Preparation of the coated silica gel with 2,4-DNPH was executed by the method of Beasley et al. (1980) with slight modification suggested by Aoyama and Yashiro (1983) with regard to the drying process and its extent. Basically, Aoyama and Yashiro recommended to thoroughly dry the coated silica gel to ensure a better reproducibility in preparation. They were making use of a rotary evaporator under reduced pressure at 55°C, same as Beasley et al. (1980).

It was found to be more efficient to dry the coated silica gel, under high vacuum pump, with heat provided by a heating mantle slightly cushioned with glass wool to ensure slower heat transfer to the round bottom flask containing the coated silica gel. Vacuum distilled dimethylformamide (DMF) kept in a sealed bottle under argon and in contact with molecular sieves was not found to yield a better coating with a lower background, consequently DMF ACS grade was used as recommended by Beasley et al. (1980).

5.2.1.4 Sampling Tubes Packing

Sampling tubes were prepared by the glassblowing technical services at the University of Alberta. The basic ideas of Aoyama and Yashiro (1983) were followed with slight modifications. Dimension and description of the glass sampling tubes are as follows: 200 mm in length by 7 mm inner diameter, the tube ends in a narrowing tip to provide a support for a glass wool plug and attachment point for tubing. The top end is finished with a ground-glass joint to provide a better sealed attachment to the generating ampoule. The generating ampoule is 200 mm in length, fitted with male and female ground glass joints at each end to fit the top of the glass sampling tube and close at the other end. The inner diameter is enlarged to 15 mm, narrowing at both ends. A side arm was also included at the top end to provide an injecting port for the aldehydes (standard recovery trials). Figure

5.1 shows the type of setting, sampling tubes and generating ampoule described above.

Packing of sampling tubes was quite simple, 1 g of 2,4-DNPH coated silica gel was placed between two glass wool plugs. Packing was performed with the help of a specially adapted funnel and packing rod, 1/8 inch stainless steel in diameter by 30 cm. Once sampling tubes were ready, they were fitted with a small diameter peristaltic pump tubing which in turn, was adapted to the Tygon® tubing leading to the pump. The pump was a Du Pont Alpha-1 constant air flow sampler with flow rate selection from 5 mL/min to 5000 mL/min. Calibration of the pumps was performed using a Cole-Parmer pre-calibrated rotameter. Different flow rates, weight of packing and type of setting were tried. Those are further discussed in sections 5.2.1.5, 5.2.1.6 and 5.2.1.8.

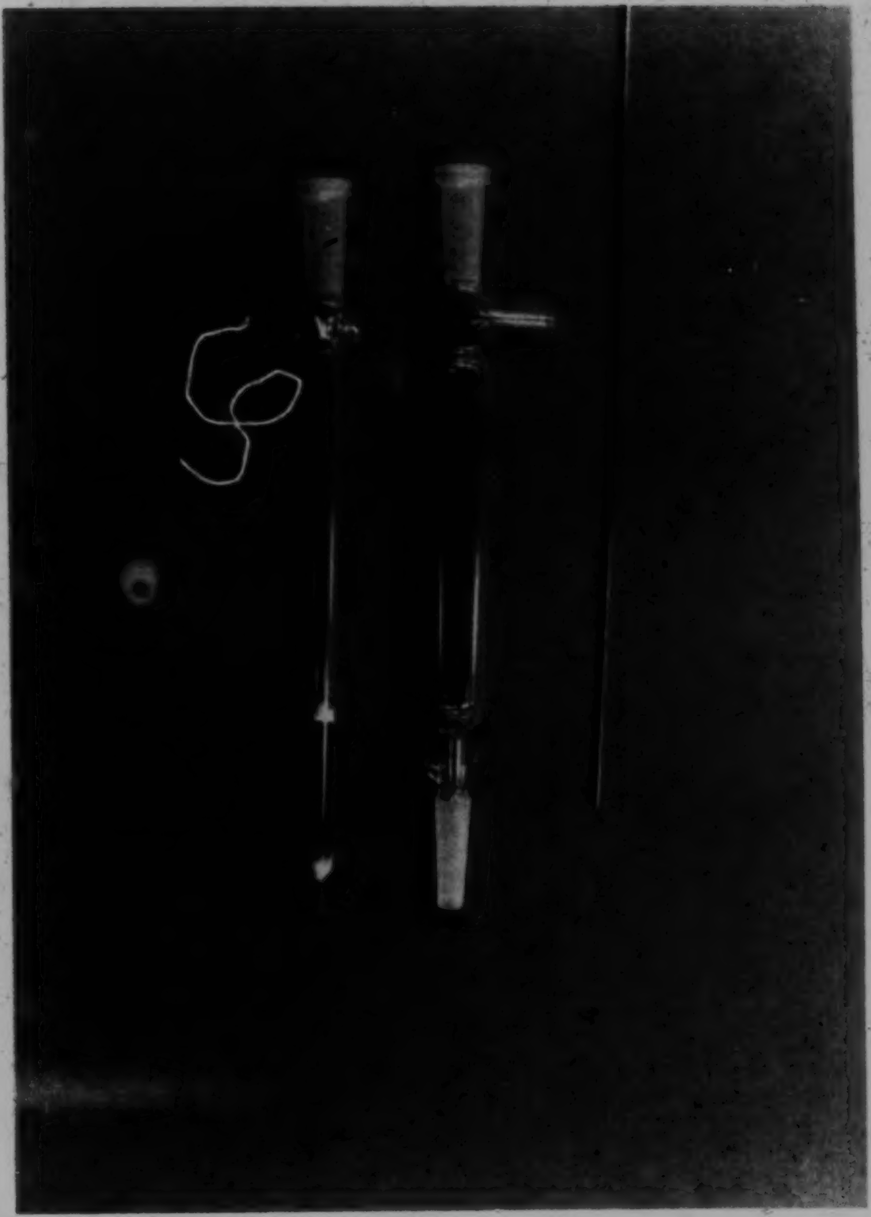


Figure 5.1 Glass Sampling Tube and Generating Ampoule for Air Sampling and Recovery Studies.

5.2.1.5 Pool Trial Set-Up

Air sampling by the adsorption tube method was performed at only one of the three sites under investigation. This latter site was selected because it presented the highest level of aldehydes in the aqueous phase.

Air sampling by the 2,4-DNPH impregnated sampling cartridges was performed on October 9, 1990 at Facility I. Sampling tubes were packed with 1 g of 2,4-DNPH coated silica gel the day prior to sampling and were wrapped in aluminium foil and stored at 4°C. The silica gel was freshly coated on October 1, 1990, and had been used for test trials at the University of Alberta pool as well as for background identification.

Sampling tubes were prepared and connected to the sampling pumps as described in the section above. Laboratory clamps and a cast iron support complete the pool side apparatus setting. The support was leaned on its side, with the rod over the water level, the clamps fixed in position and the tubes set above the water level as low as permitted by the wave motion of the water without risking flooding of the equipment (see Figure 5.2). In this position, the tubes were about 30 cm from the edge of the pool and about 20 cm above the water level.

The Alpha-1 Du Pont pumps were adjusted to flows of 1 L/min and 2 L/min on the morning of October 9, 1990 just prior to sampling with a Cole-Parmer rotameter. Sampling times were controlled by the computerized pump and were adjusted for 1 h and 30 min, respectively. At the end of each sampling, the two available pumps were fitted with a new sampling tube and positioned at a new sampling location indicated on Figure 5.3, until all predetermined sampling locations were tested. The sampling tubes were wrapped in aluminium foil and brought back to the University of Alberta for extraction.

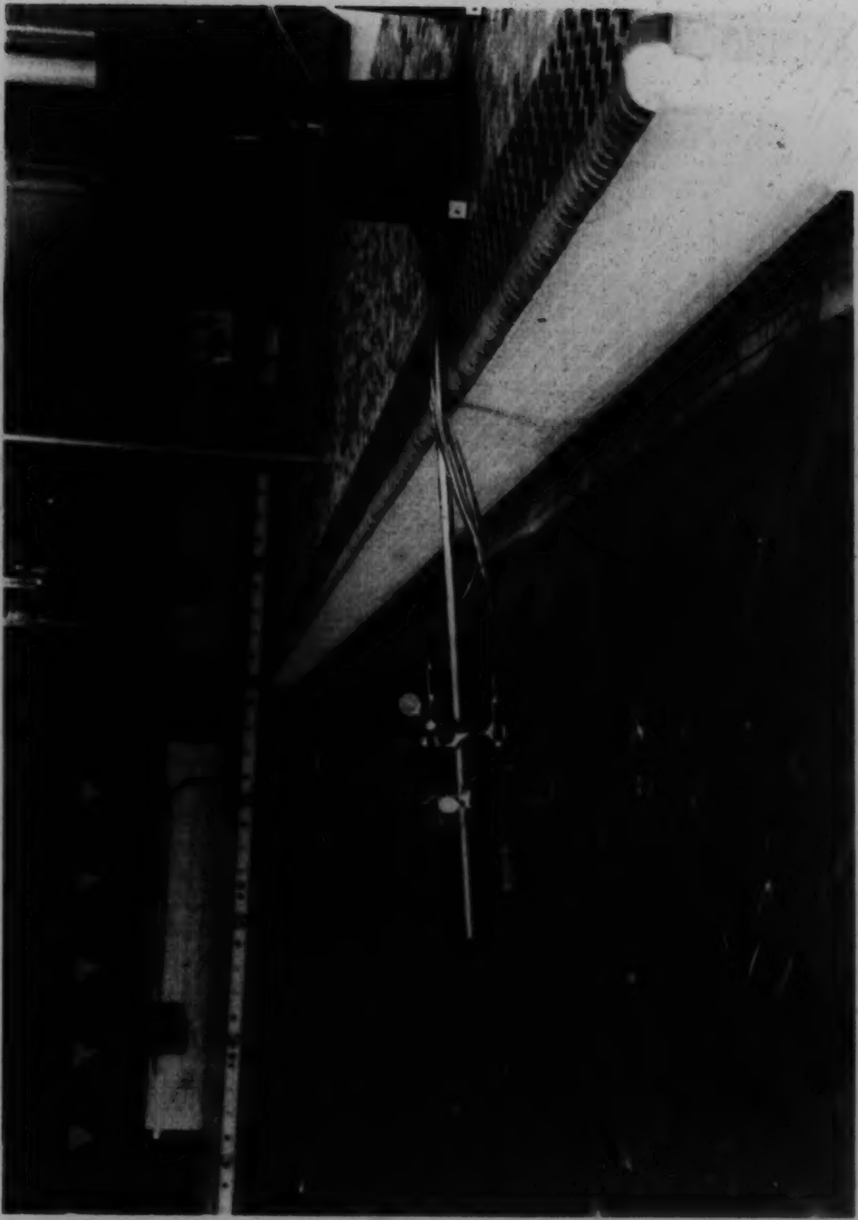


Figure 5.2 Typical Air Sampling Apparatus at a Swimming Pool Site.

Preliminary work was performed with carbon tetrachloride (CCl_4) extraction solvent with 1,3-dibromopropane (DBP) as an internal standard, followed by exchange to ethyl acetate (EtOAc) and subsequent analysis on GC/ECD. Exchange in EtOAc was necessary because the ECD detector is sensitive to halogens and would be saturated by the halogenated solvent. Since the detection was not sufficiently sensitive for the DNPH derivative, subsequent work was performed on a GC/FID. The internal standard was changed to anthracene to obtain a better response on the FID detector. Since DBP is a small molecule with only three carbon atoms, the detection on FID is limited. CCl_4 was kept as the extraction solvent and exchanged to EtAOc to prevent deterioration of the detector. Hydrochloric acid (HCl) forms from the use of chlorinated solvents in conjunction with heat from the injector port and can result in corrosion of the detector.

The extraction of the hydrazone follows the procedure described in section 5.2.1.7. The internal standard used at this stage was DBP and Bio-Rad resin (AG 50W X8) was used in the clean-up step.

The use of Bio-Rad resin was supposed to help in cleaning up the background and unreacted 2,4-DNPH. A method blank was also performed by extracting unused coated silica gel by the heating method described above and filtering over Bio-Rad resin.

The Bio-Rad resin was previously washed according to the procedure described by Schwartz et al. (1962). The extraction solvent and resin cleaning solvents were made carbonyl free following the procedure of Johnson et al. (1981) and Hornstein and Crowe (1962). Other resins that were available in the Department were also tried for clean-up purposes without much success. They included: 'pre-used' AG 50W X8, 'original Dowex' AG 50W X8, 'pre-used Baker' AGC-244 (relabelled as equivalent to AG 50W X8) and the newly purchased Bio-Rad AG 50W X8. A no resin clean-up experiment was also performed to establish the quality of the clean-up step. Later experiments were performed without the use of resin for the filtration.

5.2.1.6 Testing of Recovery

Two different settings were tried under the recovery trial experiments. The settings differed by the mode of introducing the aldehyde to the generating ampoule, the magnitude of the nitrogen flow and the position of the nitrogen flow entrance. Sampling tubes were prepared as described in the sampling tube packing section above, they were mounted according to the two different settings shown in Figures 5.4 and 5.5. The first setting provided an upper entrance for the nitrogen flow of 20 mL/min with a side arm aldehyde injection through the septa. It was an open system, since air was drawn from the top were the nitrogen flow was introduced. The nitrogen flow was introduced at 70 kPa from the gas cylinder to an additional manometer in series with the gas cylinder and the sampling tube. This second manometer allow an accurate calibration of a lower gas flow rate (20 mL/min). The second setting was a closed system with no air being drawn into the system. Both the aldehyde injection and the nitrogen were introduced through the side arm fitted with peristaltic pump tubing in series with the gas cylinder. The top opening was fitted with a ground glass joint stopper. The nitrogen is introduced at a pressure of 55 kPa from the gas cylinder manometer by-passing the second manometer used in the first setting. The larger nitrogen pressure was necessary to compensate for the absence of air drawn to the system. Heat-by-the-yard® heating tape provided the heat required to volatilize the standard aldehyde introduced in the generating ampoule. The aldehyde was introduced into the heated generating ampoule as a solution in hexane with a 10 µL Hamilton® syringe. The application of nitrogen flow and the suction action provided by the pump ensured that the volatilized aldehyde contacted the coated silica gel in the sampling tube. In doing so, it reacts to form the hydrazone and adsorbed to the surface of the silica gel which is then extracted. The pumps were activated for 1 h at a flow rate of 1 L/min. A method blank was also analyzed to account for any contamination from the prepurified nitrogen gas, as well as, background levels. A stock solution of the aldehyde was prepared and different volumes were spiked to give a range of concentrations at the desired level.

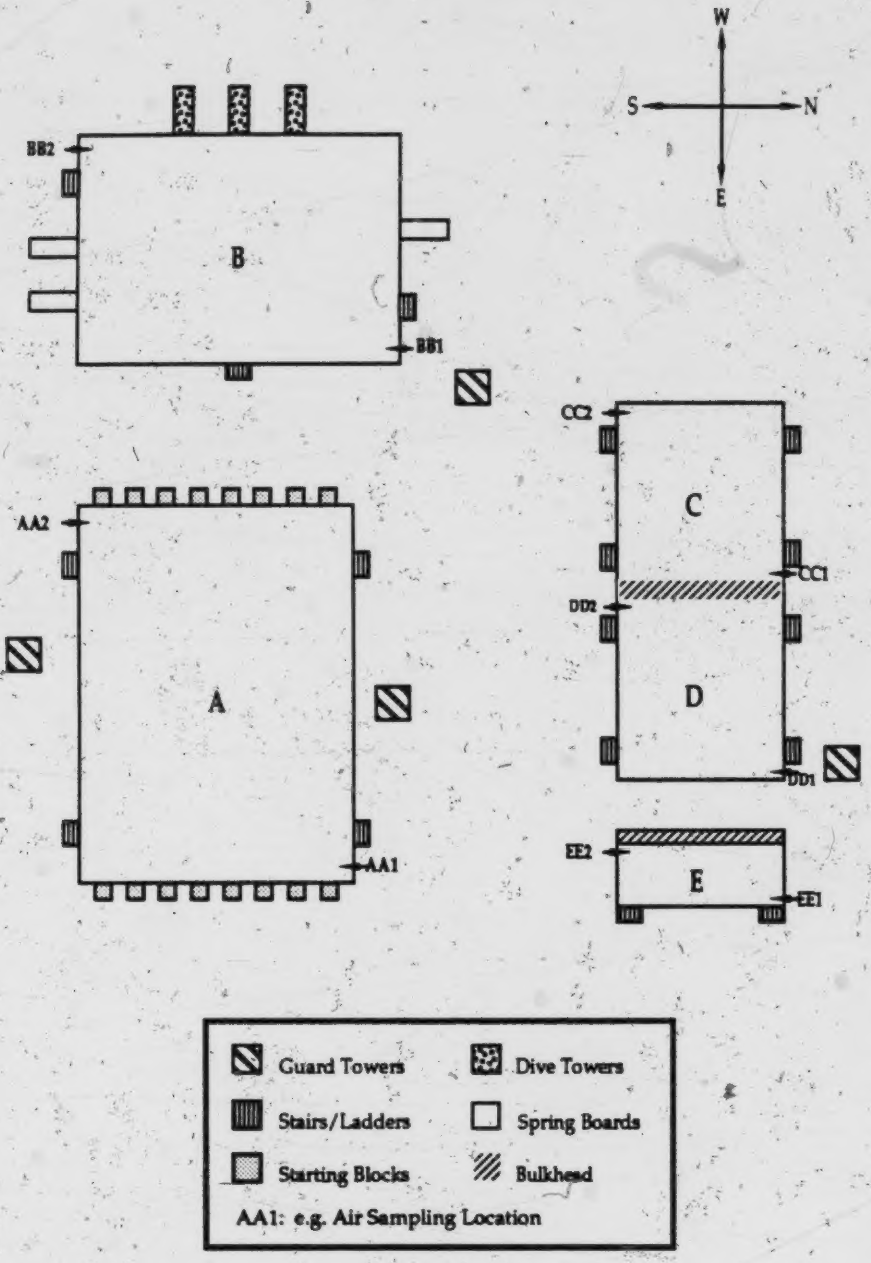

W
S
N
E
BB2
B
BB1
CC2
C
CC1
DD2
D
DD1
AA2
A
AA1
EE2
E
EE1
Guard Towers
Dive Towers
Stairs/Ladders
Spring Boards
Starting Blocks
Bulkhead
AA1: e.g. Air Sampling Location

Figure 5.3 Air Sampling Location for the Adsorption Tube Method on October 9, 1990 at Facility I.

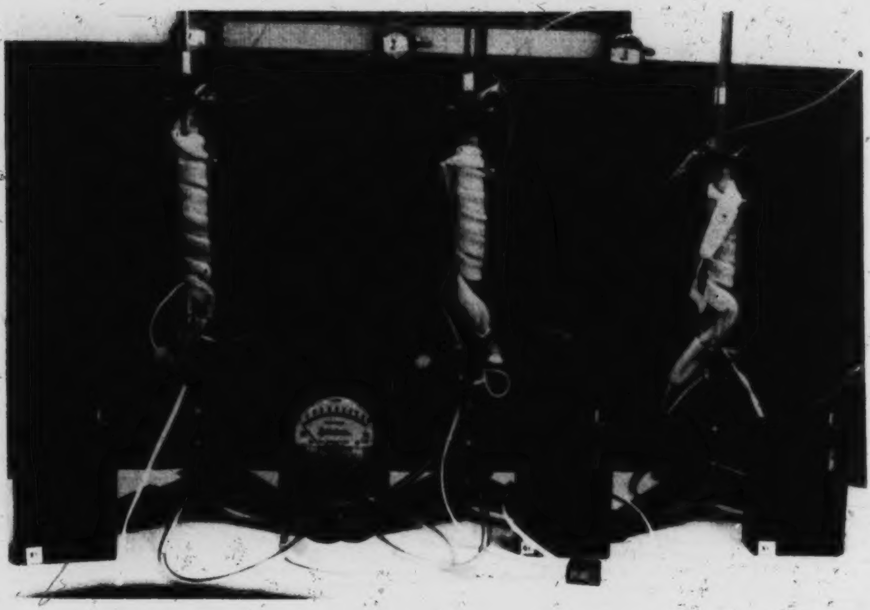


Figure 5.4 Setting for the Open System Air Sampling Recovery Study with Generating Ampoule.

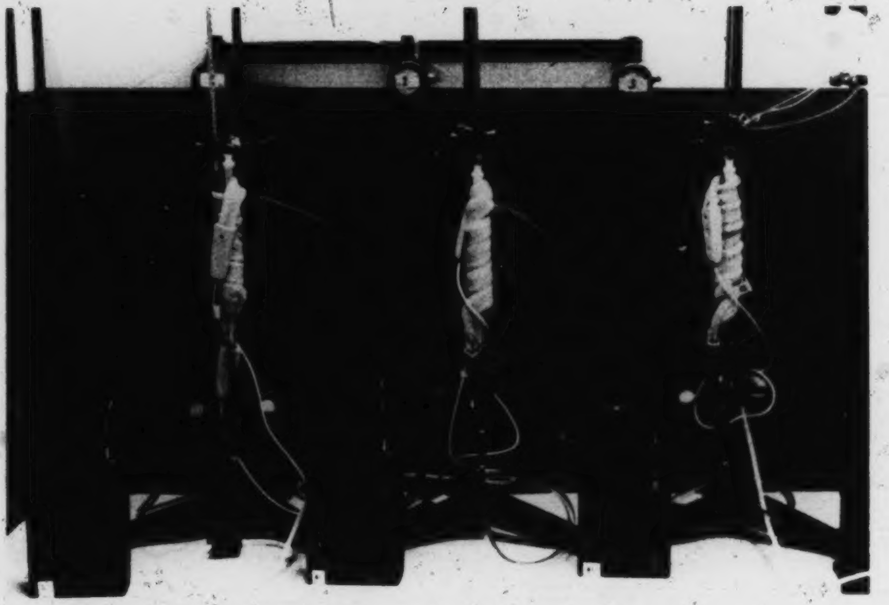


Figure 5.5 Setting for the Closed System Air Sampling Recovery Study with Generating Ampoule.

5.2.1.7 Extraction of Hydrazones from Coated Silica Gel

The hydrazone was extracted by transferring the glass wool plugs to a 20 mL screw-cap glass vial (with Teflon®-lined silicone septum) and the coated silica gel in 8 mL of carbon tetrachloride (CCl_4). An additional 2 mL of CCl_4 was used to rinse the glass sampling tube. The 10 mL extract was heated to 50°C on a Pierce Reacti-Therm® heating module for 10 min, cooled to room temperature and filtered through a glass wool plug inserted in a Pasteur pipette into a clean 40 mL glass Fisher brand vial. Some preliminary work was also performed using resin as a clean-up step. The extract volume was then reduced under a flow of nitrogen and exchanged with ethyl acetate (EtOAc) containing anthracene as internal standard. Aoyama and Yashiro (1983) had reported no suitable internal standard when using CCl_4 and GC/FID. By transferring to EtOAc it was possible to use anthracene as internal standard, since the solubility of anthracene is greater in EtOAc than in CCL_4. Also, EtOAc is a friendlier solvent to use on an FID detector, since CCl_4 burns to form HCl which can damage the detector.

5.2.1.8 Testing with Controlled Water Basin

Since non-detectable aldehyde results were obtained from sampling at swimming pool sites, an attempt to explain the "no recovery" by the adsorption tube was investigated with a controlled water basin. Knowing the concentration of aldehydes in the aqueous phase at the swimming pool, it was possible to predict the maximal concentration that could be observed in the air phase (Mackay et al. 1979, Dong and Dasgupta 1986). Prediction of the maximal concentration that could be found in the overlying atmosphere above the water was performed using the physical characteristics of the chemical compound of interest that describe the partition behaviour between the two phases.

The partition coefficient that best describes a gas-liquid system at equilibrium, assuming ideal fluid behaviour (Montgomery 1985) is given by the Henry's law constant. Henry's law constant for the two most prevalent aldehydes in the water phase of the swimming pool were found in the literature.

Betterton and Hoffmann (1988) have studied seven aldehydes that are found to be of particular importance in the polluted troposphere. The Henry's law constants were determined as a function of temperature by bubble-column and head-space techniques. The Henry's law constant for formaldehyde and acetaldehyde at 25°C in units of $M \ atm^{-1}$ are 2.97×10^3 (or 3.37×10^{-4} $atm \ M^{-1}$) and 1.14×10^1 (or 8.77×10^{-2} $atm \ M^{-1}$), respectively. These latter constants can be used following the equations reported by the same authors to calculate the maximal concentration in the overlying atmosphere in the enclosed swimming pool. The conditions surrounding the facility do not represent, as must be the case when using the equations, a gas-liquid system at equilibrium under optimum conditions but nevertheless the calculations can be used to provide an estimate of the maximum expected of aldehyde concentration in the air phase.

The present authors have followed the reaction (see 5.1) that best described their experimental setting, that is they were forcing the gas to the aqueous solution. As a result the units and values for the apparent Henry's law (H^*) and the intrinsic Henry's law constant (H) are the reversed of the conventional way of reporting these values.

(5.1) gas (g) → aqueous solution (aq)

In the following development the Betterton and Hoffmann equations are modified to conform with the convention. That is the reaction (see 5.2) that describes the gas leaving the aqueous phase will be applied (stripping effect) (Montgomery 1985).

(5.2) aqueous solution (aq) → gas (g)

The first set of equations shows the relationship between the hydration constant (K_{hyd}) of aldehydes in the water, the apparent Henry's law constant (H^*) and intrinsic Henry's law constant (H). The relation is as follow:

Equation 5.1 $$H = \frac{[RCHO]_g}{[RCHO]_{aq}} \quad \text{in} \quad \text{atm-m}^3\ M^{-1}$$

Equation 5.2 $$H^* = \frac{[RCHO]_{aq} + [RCH(OH)_2]}{[RCHO]_g} \quad \text{in} \quad \text{atm-m}^3\ M^{-1}$$

Equation 5.3 $$K_{hyd} = \frac{[RCH(OH)_2]}{[RCHO]_{aq}}$$

where: $[RCHO]_{aq}$ is the concentration of free aldehyde, unhydrated, dissolved in the aqueous phase;

$[RCHO]_g$ is the concentration of aldehyde in the gaseous phase;

$[RCH(OH)_2]$ is the concentration of aldehyde present in the *gem*-diol, hydrated, form.

The total aldehyde concentration in the aqueous phase $[RCHO]_t$ is given by Equation 5.4:

Equation 5.4 $$[RCHO]_t = [RCHO]_{aq} + [RCH(OH)_2]$$

Rearrangement of the previous equations gives the direct relationship between H^*, H and K_{hyd}:

Equation 5.5 $$1/H^* = 1/H(1 + K_{hyd}) \quad \text{or}$$

$$H = H^*(1 + K_{hyd})$$

When $K_{hyd} >> 1$, i.e., when $[RCH(OH)_2] >> [RCHO]_{aq}$, then Equation 5.6 applies:

Equation 5.6 $$H^* \approx \frac{[RCHO]g}{[RCH(OH)_2]} = H/K_{hyd}$$

The experimental results obtained yield H^*. With H^* and the concentration in the aqueous phase, it is possible to calculate the aldehyde concentration in the gas phase by combining and modifying Equations 5.2 and 5.4:

Equation 5.7 $$[RCHO]g = [RCHO]_t \times H^*$$

$[RCHO]_t$ is given by the aldehyde method described earlier for measurement of the concentration in the aqueous phase (section 5.1.2).

From Equation 5.7, the amount to be found in the gaseous phase can be estimated for a known concentration in the aqueous phase. This is the basis of the controlled water basin experiment undertaken. A given volume of deionized water was spiked with formaldehyde and acetaldehyde and the aqueous phase concentration was establish by the PFBOA method. Sampling tubes were prepared and connected to pre-calibrated pump units. In the first trial, the sampling tube was adapted with a large funnel (150 mm in diameter) with multiple sizes of vacuum tubing and Tygon® tubing. In the second trial, the small packing funnels (50 mm in diameter) were used. The first setting was adjusted just 1 cm above the water level (see Figure 5.6) and the second setting just 5 mm above the water level (see Figure 5.7). Recovery results with the first setting were low and it was thought that perhaps to much tubing and funnel could act has adsorption sites for the aldehydes. Consequently a second experiment was tried. A shorter pathway was hoped to provide greater recovery. Results are presented in the Results and Discussion section.

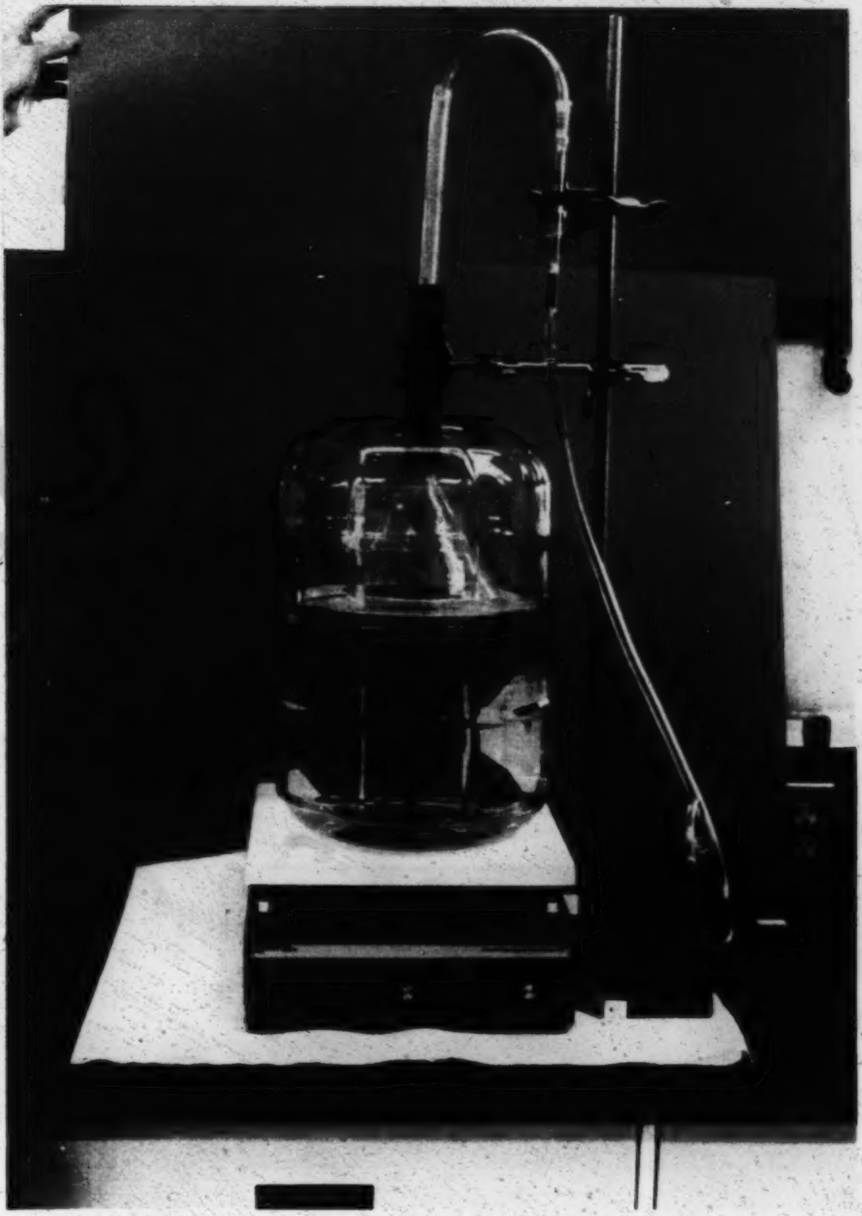


Figure 5.6 Air Sampling with Controlled Water Basin and Large Funnel.

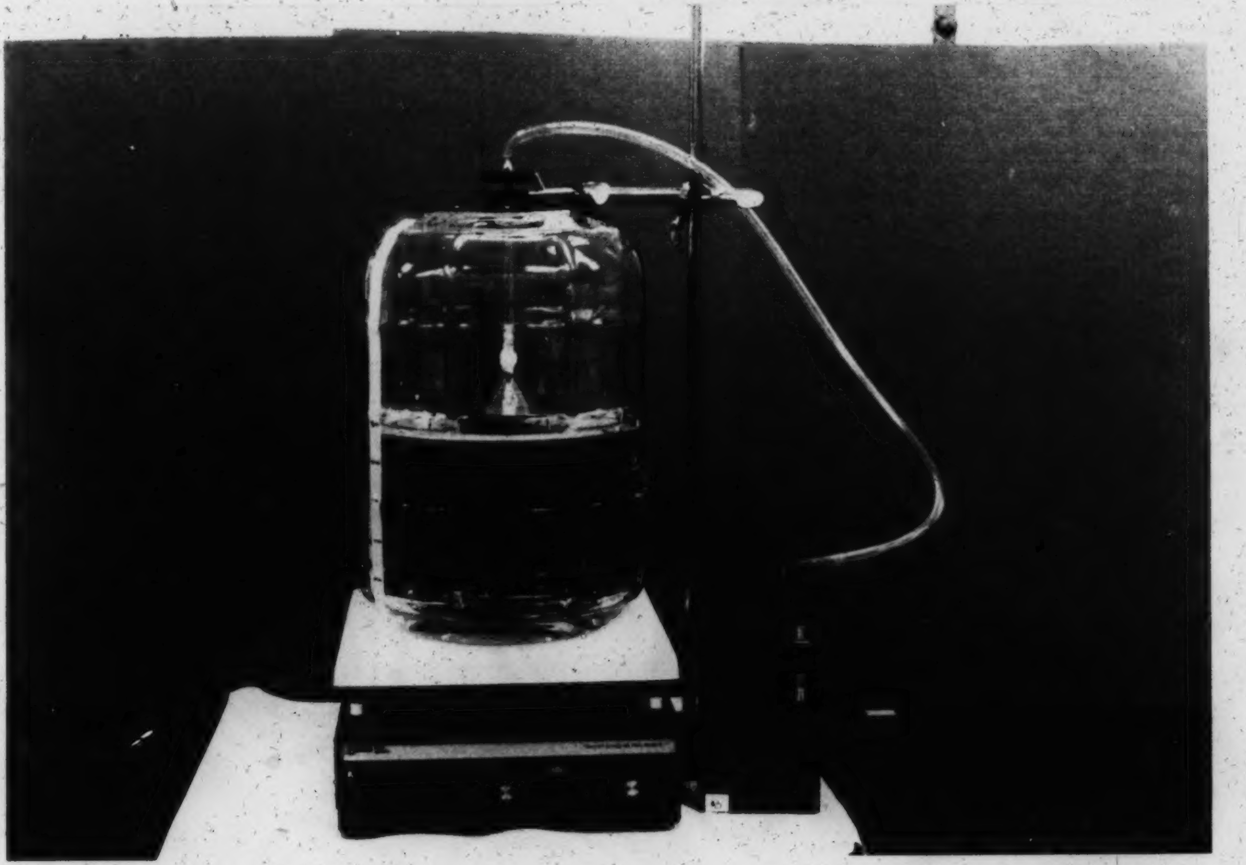


Figure 5.7 Air Sampling with Controlled Water Basin and Small Funnel.

5.2.2 Air Bag Sampling

As in the case for air sampling by the adsorption tube method, only one site out of the three was surveyed. Overlying atmosphere over Pool I-E, containing the highest concentration of waterborne aldehydes, was sampled by the air grab sampling technique. Grab sampling implies that a certain volume of air is sampled, with a sample device and later analyzed by either a chromatographic or a non-chromatographic method of detection as described in section 2.2.2 (Otson and Fellin 1988). The following procedure was followed for the air grab sample.

5.2.2.1 Swimming Pool Samples

A Tedlar® polypropylene 40 L sampling bag with dual stainless steel valves was connected to an SKC Aircheck sampler model 224-43XR with Tygon® tubing (see Figure 5.8). The flow rate was set such that 40 L would be sampled in 8 minutes (5 L/min). The sample was taken approximately 30 cm above the water level.

The sample was subsequently analyzed by Fourier Transform Infrared (FTIR) detection, making use of the physical properties of the chemicals for detection. More specifically, rotational-vibrational spectrum were recorded at specific IR absorption bands for the different molecule functionalities. FTIR detection methods permit simultaneous monitoring of several classes of compounds (Li-Shi et al. 1989).

Additional features which favour this method of detection as an air monitoring tool are: its very low limits of detection (LOD) (Strang and Levine 1989), its near real-time identification and its ability to quantify gases and vapours (Li-Shi et al. 1989).

The system used was a Nicolet 7199 FTIR. It is equipped with a 5.6 L Wilks gas cell with a single by-pass of 0.75 m. Analysis were run at atmospheric pressure and room temperature. Runs were performed to accumulate 20.25 m under a single wave length resolution permitting increased resolution between two wave lengths. The system is completed by a mercury-cadmium-telluride (MCT) detector providing a very good sensitivity. The detector is cooled at liquid nitrogen temperature.

5.2.2.2 Aldehydes Spiked Samples

Because results obtained from the grab sample analysis were also negative for aldehydes an attempt to further evaluate the potential of FTIR detection as an appropriate method of detection in the air sampling analyses at swimming pools was investigated. Two-step injection of formaldehyde and acetaldehyde was performed to insure that moisture bands would not interfere with aldehyde detection and that individual detection of each aldehyde could be performed.

A grab air sample from the swimming pool was spiked with 10 ppm of formaldehyde, FTIR analyses was performed and background analysis from the initial swimming pool air sample was subtracted. In a second step, acetaldehyde was added, at a level of 20 ppm, to the air sample previously spiked with formaldehyde and FTIR analysis was performed. Again background analysis was subtracted and the formaldehyde spiked result was also subtracted. Results are presented and discussed section 6.

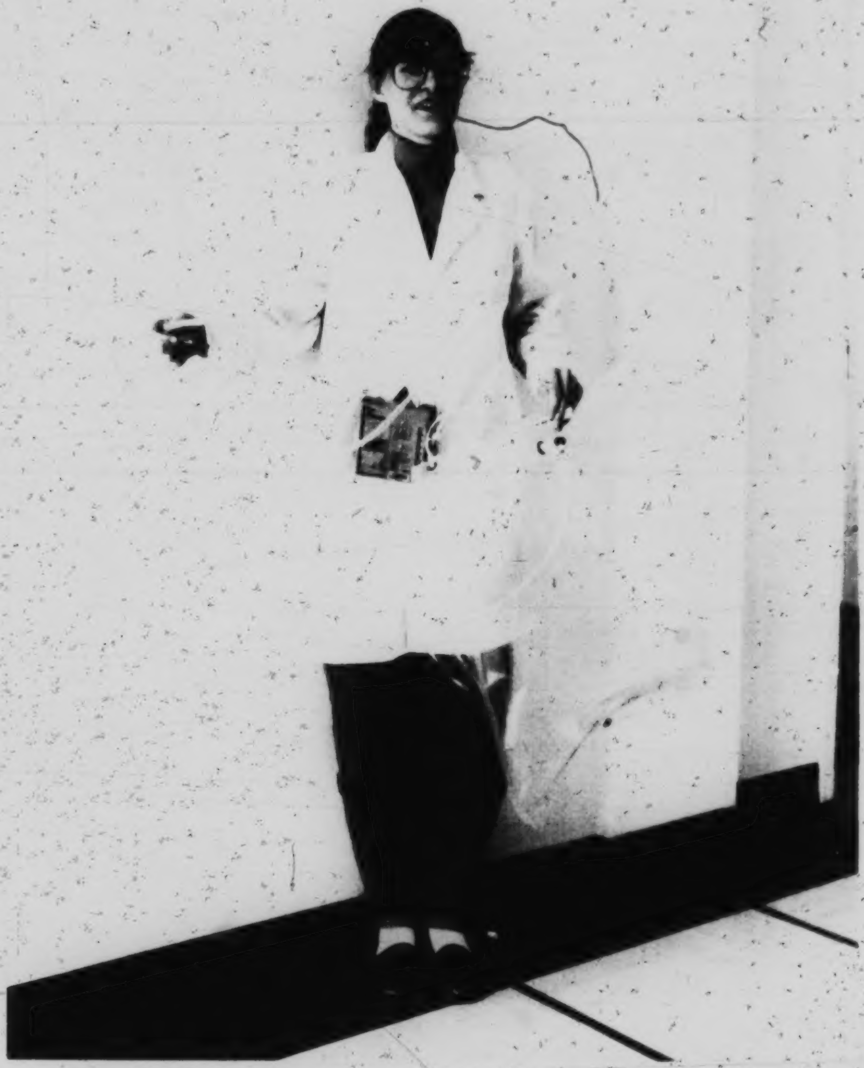


Figure 5.8 Tedlar® Sample Bag with SKC Sampling Pump.

5.3 Microbial Analysis of the Water

Samples for the microbial analysis of water were obtained from the sampling sites stipulated under Alberta Regulation 247/85, Public Health Act, Swimming Pool Regulation. The samples were obtained from the swimming pool from a point near an outlet and from additional points to give an accurate representation of the water in the pool. This requirement determined the sampling locations for all the analyses performed for the water phase, in order to facilitate comparison between the chemical and microbial profiles.

Samples for microbial analysis were collected in sterile 500 mL polypropylene bottles with wide mouth screw-caps. The bottles were immersed and sealed underwater when sampling. Three 500 mL bottles were sampled at each sampling point. Whirl-Pak® polyethylene sterilized bags (530 mL) also had to be used for sampling. Four bags needed to be filled at each sampling point. The samples were dechlorinated with sodium thiosulfate as per section 9060 A (Standard Methods), recapped (or sealed) and stored at 4°C in the dark until analyzed. The dechlorination of the samples took place at the site of sampling. Samples were kept in ice cooled coolers for travelling purposes. Samples were analyzed within 30 hours of collection.

The microbial analysis were performed for the most part at the University of Alberta, Environmental Engineering and Science by Karen M.E. Emde, microbiologist. Microbial analysis under Alberta Regulation 247/85 stipulate that the following indicator organisms are required: Total heterotrophic bacteria, determined by the standard 35°C plate count, total coliforms and *Pseudomonas aeruginosa* in waters above 30°C. Additional tests were also performed to survey for other microbial indicators. Bacteriological analyses were performed, in triplicates, according to the respective Standard Methods for the Examination of Water and Wastewater 17th edition (Standard Methods) sections, as follows. Total coliforms (TC) were enumerated by the membrane filtration technique according to 9222B and Fecal coliforms (FC) according to 9222D of Standard Methods. *Klebsiella* is a genus included in the coliform group and may be associated with coliform regrowth in treated water. It was analyzed for by using the membrane filtration technique describe in section 9222F of Standard Methods. Total heterotrophic plate counts (HPC) were performed as per 9215B of Standard Methods. Fecal streptococci were determined by method 9230C described in Standard Methods. The membrane filtration technique described in section 9213E was used to test for *Pseudomonas aeruginosa*.

Mycobacterium species were analyzed by the Mycobacteriology Laboratory Division of the Provincial Laboratories, because of the very high pathogenicity of the microorganisms and the need for special containment.

5.4 Microbial Analysis of the Air Phase

5.4.1 Description of the Air Sampler and Characteristics of Operation

Microbial analyses of the air phase were performed using a Biotest RCS Centrifugal Air Sampler (see Figure 5.9). The air sampler is a completely portable, hand-held apparatus weighing 1.1 kg which operates on four standard "D" cell batteries and can be used in any direction. It provides an estimate of the number of microbial colony forming units in room air or other environments, thereby permitting a microbiological assessment of air quality . The sampling times are switch controlled and range from 30 seconds to 8 minutes, offering an air capacity of 20 to 320 litres at a separation volume of 40 L/min. Sampled air volume is electronically controlled to an accuracy of ± 2.0%. The air sampler employs efficient agar impaction as the collection principle. The media strips are commercially available in different media for bacterial and fungal analyses.

5.4.2 Operation Principle

The Biotest air sampler works on the impaction principle. The function of the air sampler is to collect airborne microorganisms quantitatively onto a culture media strip mounted around the drum of an impeller. The air under investigation is sucked in by the impeller at a distance of at least 40 cm in a conical shape and enters the impeller drum portion centrifugally. Airborne particles are forced to impact on the culture media contained in the plastic strip. The air then leaves the drum in a spiral form around the outside of the cone of air entering the sampler. After the air sample has been taken, the agar strip is removed, incubated and the colonies are counted. Figure 5.9 shows the Bio-Test aerosol monitor and insertion of the agar strip.

Figure 5.9 Biotest RCS Centrifugal Air Sampler for Aerosol Monitoring.

5.4.3 Sampling Procedure

Sampling time was set at 8 minutes for all samples. The agar strip was removed from the plastic wrapper and inserted into the slot of the open-end drum with the agar surface facing towards the blade of the impeller. Once the sampling point was chosen, the sampler was switched on and pointed towards the sampling point, keeping it above the water level to protect it from splashing. At the end of 8 min, the air sampler stops automatically, the strip was removed and replaced in the plastic wrapper, and closed with a piece of tape. The agar strip was handled by the edge at all times when removed from the plastic wrapper. Two different medium were used at each sampling points: Agar strip GK-A (TSA-Agar for total count) and Agar strip HS (Rose-Bengal-Agar for yeasts and moulds). The agar strips were transported in an insulated container to prevent from freezing (winter season travelling) and incubated for 18 h at 37 °C upon arrival at the University of Alberta. Karen E.M. Emde performed the bacterial and fungal counts on the respective agar media.

6. RESULTS AND DISCUSSION

6.1 Water Analysis

6.1.1 Aldehydes

Aldehyde analyses were performed following the method initially described by Yamada and Somiya (1989) and subsequently improved by Glaze et al. (1989). Further slight laboratory modifications, described in section 4.1.1, were added to the Glaze et al. method. In order to account for the analysis delay, and possible degradation of sample during storage in coolers, different experiments were tried on samples from the different pools. Extensive detailed aldehyde results can be found in Appendix D1.4. The following information will highlight the main observations.

The series of experiments include a study on the preservation treatment with sodium thiosulfate, namely: addition of sodium thiosulfate immediately following sample collection (S_2O_3 added within 1 h), and addition of sodium thiosulfate immediately before analysis (S_2O_3 added IBA). A study on the delay of analysis was also performed, as per the following protocol: sodium thiosulfate was added immediately after collection of sample (S_2O_3 added within 1 h) and the sample was stored in the dark at 4°C for 48 h before analysis was completed (analysis delay of 48 h).

The aldehyde results obtained from the different treatments in the preservation-delay study, for the July 26, 1990 samples from Pool I, are illustrated in Figures 6.1 and 6.2. As can be seen from the figures, only very small concentration variations are found between the different results for preservation treatment and delay of analysis experiments. Formaldehyde is slightly more affected than acetaldehyde. These two aldehydes represent the most prevalent aldehydes.

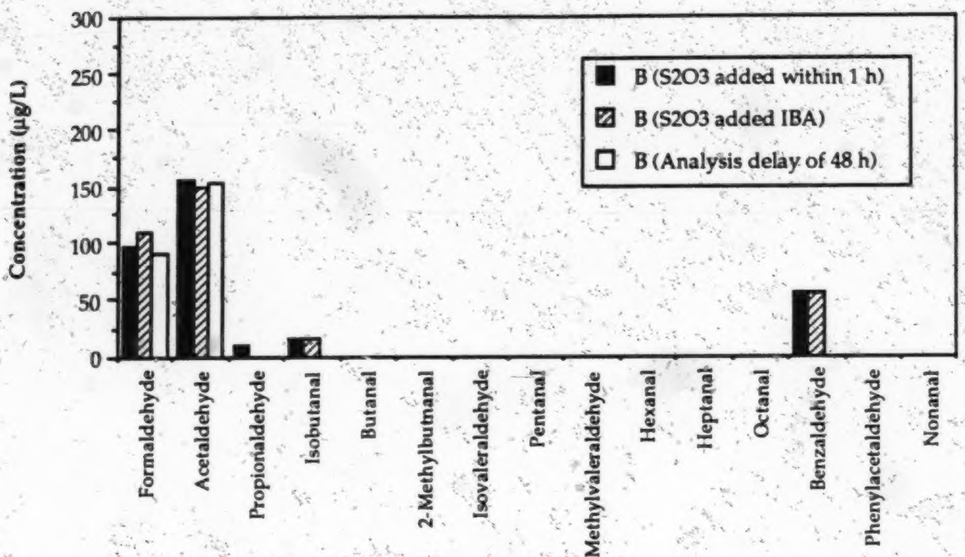


Figure 6.1 Aldehyde Analysis for Pool I-B on July 26,1990. Studies Comparing Preservation Treatment with Sodium Thiosulfate (S_2O_3) and Analysis Delay.

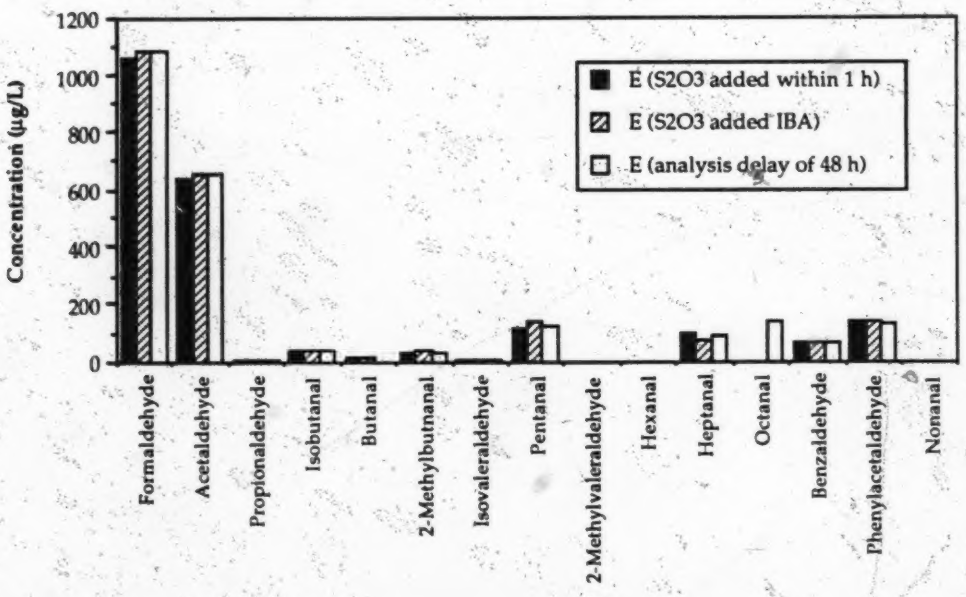


Figure 6.2 Aldehyde Analysis for Pool I-E on July 26,1990. Studies Comparing Preservation Treatment with Sodium Thiosulfate (S_2O_3) and Analysis Delay.

The maximum deviation observed in the case of formaldehyde is +16%, between preservation treatment in the case of Pool I-D. Results obtained following a 48 h delay in analysis, with storage at 4°C, are slightly lower with a maximum deviation of -11% for Pool I-A, while one case out of five presents a higher result by +2%, Pool I-E. Acetaldehyde presents its maximum deviation at -29% in Pool I-A, comparing results from analysis delay to preservation treatment within 1 h. Note that this latter result was used as the "true value" for purpose of evaluating the deviation. The acetaldehyde results present no generalized behaviour for the samples after 48 h delay before analysis, as can be observed in Figures 6.1 to 6.5.

The lower concentration aldehydes are at their level of detection on the gas chromatograph and therefore were of lesser importance in this preservation-delay study. Their lower levels would also suggest that their part as potential irritants might be minimal in comparison with the level of the known irritants formaldehyde and acetaldehyde.

The largest variety of aldehydes was found in the wading pool, identified as Pool I-E in Figure 4.1. Of the 15 aldehydes tested for, 11 were found in Pool I-E, while only 8 or less were found in the other pools, with Pool I-B being the cleanest pool with respect to aldehydes. Pool I-E, also presents the highest concentration of total aldehydes and individual aldehydes to be found in comparison with the other pools at the same site. A concentration of 1057 μg/L of formaldehyde can be found in Pool I-E, while the other pools has formaldehyde concentrations ranging from 97 μg/L to 178 μg/L, a ratio of 9 to 17%.

The differences in observed aldehydes can probably be explained based on an organic loading and/or on temperature basis. Pool I-E provides a low dilution capacity (38 m^3), combined with a higher ratio of bather load, i.e.

weight of organic load/volume of water. Pool I-E is also the warmest pool at the site, which would increase dissolution of organic material from bathers and chemical reaction rates. Pool I-E has the fastest turn over rate, at 50 minutes per pool exchange, it still does not compare with the much higher dilution capacity offered by the other swimming pools at the facility: Pool I-A, 2082 m^3; Pool I-B, 1522 m^3 and Pool I-C and D combined, 572 m^3 (see Figure 4.1 and Appendix B).

Individual swimming pool profiles did not show important concentration changes at the sampling locations in the individual tanks. Individual swimming pool profiles were obtained for July 30, August 1 and August 6, 1990 for all tanks at Pool I. In each case, the same observations prevail. No substantial change in concentration was observed for any of the aldehydes found among the different sampling locations in each individual tank. Figure 6.3 and 6.4 illustrate these observations, note that the average was plotted against all three sampling locations. These figures represent a low and a high range of concentration with respect to formaldehyde and acetaldehyde.

Aldehyde concentration differences are only observed between the different days of analysis, which could account for "short term seasonal change". Again, the most striking differences are with formaldehyde, followed by acetaldehyde, while the higher molecular weight aldehydes remain fairly constant and at much lower levels by a factor of 8 to 10 (refer to Figures 6.3 and 6.4). Exceptions are benzaldehyde and phenylacetaldehyde, which are usually 2 to 3 times less than their lower molecular weight counterparts, formaldehyde and acetaldehyde in each individual pool. Acetaldehyde generally prevails over formaldehyde, with the exception of Pool I-E, were formaldehyde takes over as the primary aldehyde (see Figures

6.5 and 6.6). On one occasion (July 26, 1990 results) formaldehyde levels were almost double that of acetaldehyde.

These earlier results from July and August were all sampled before an extensive annual cleaning operation at Pool I. The following observations for October and November were obtained after the pools had been emptied, cleaned and repaired before they were refilled with fresh treated water. Filtration units, part of the treatment process, were also cleaned at that time.

In the second phase of the sampling program at Pool I, a daily time profile was established through the same pool profile sampling used in the first phase. In total, 45 aldehyde samples were obtained for each day of sampling: 3 sets of samples (for daily time profile) for each individual sampling location (15 sampling location, pool profile) on the 2 different days, about 2 months apart.

As it was found in the first phase of the sampling program, the pool profile results are very consistent and the 3 samples can be averaged to one result in the second phase as well. On the other hand, there is a "slight time profile" with the lower molecular weight aldehydes, formaldehyde and acetaldehyde. As for the higher molecular weight aldehydes, changes throughout the day are not marked, with the exception of 2-methylvaleraldehyde and benzaldehyde which seem to appear as the day advances but remain at fairly low constant concentrations once they are found (see Figures 6.7 and 6.8). The higher molecular weight aldehydes, when present, are found to about the same level as in the first phase. The lower molecular weight aldehydes, are in much higher concentration than in phase one and again in much higher concentrations than their higher molecular weight counterpart in the same phase.

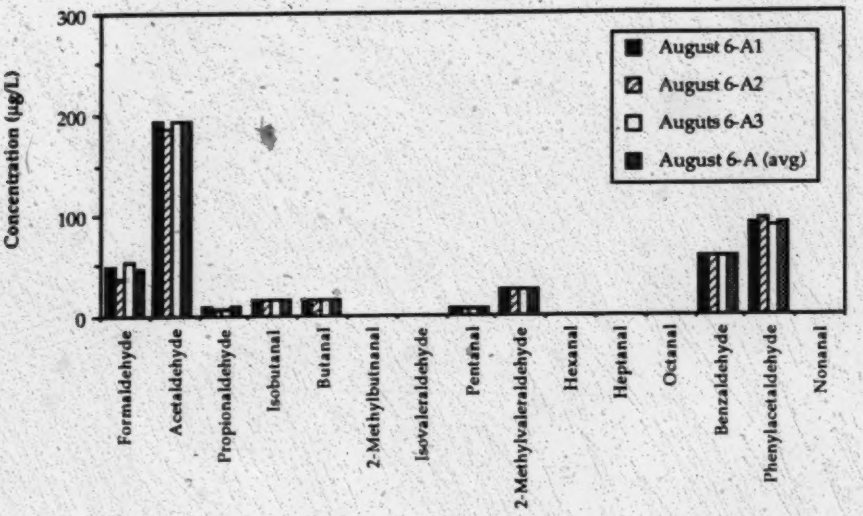


Figure 6.3 Aldehyde Analysis for Pool I-A on August 6, 1990. Study Showing Pool Profile with Respect to Different Sampling Locations.

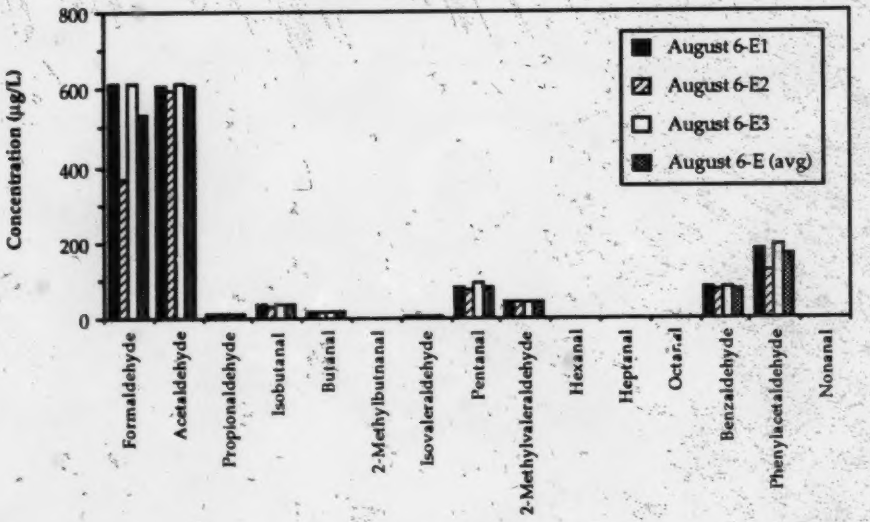


Figure 6.4 Aldehyde Analysis for Pool I-E on August 6, 1990. Study Showing Pool Profile with Respect to Different Sampling Locations.

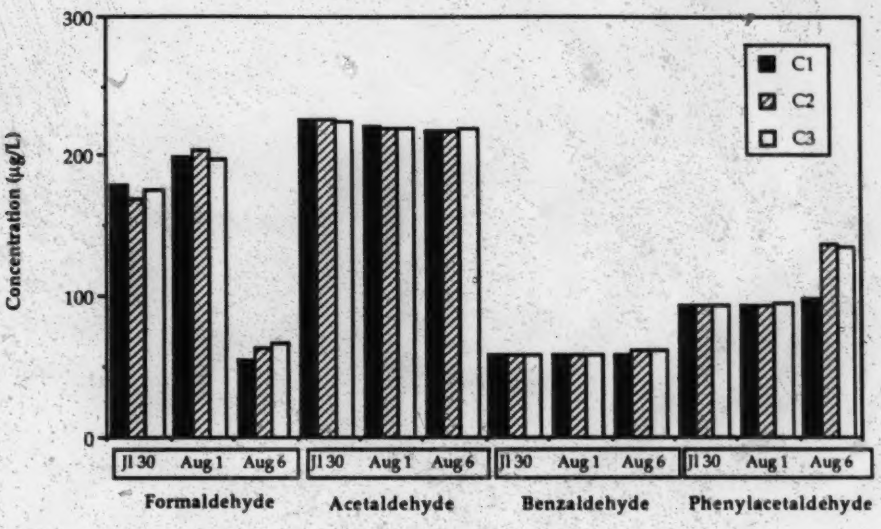


Figure 6.5 Aldehyde Analysis for Pool I-C. Example of Homogeneous Pool Profile on a Single Day Combined with Seasonal Profile. (See Figure 4.2 for Sampling Locations)

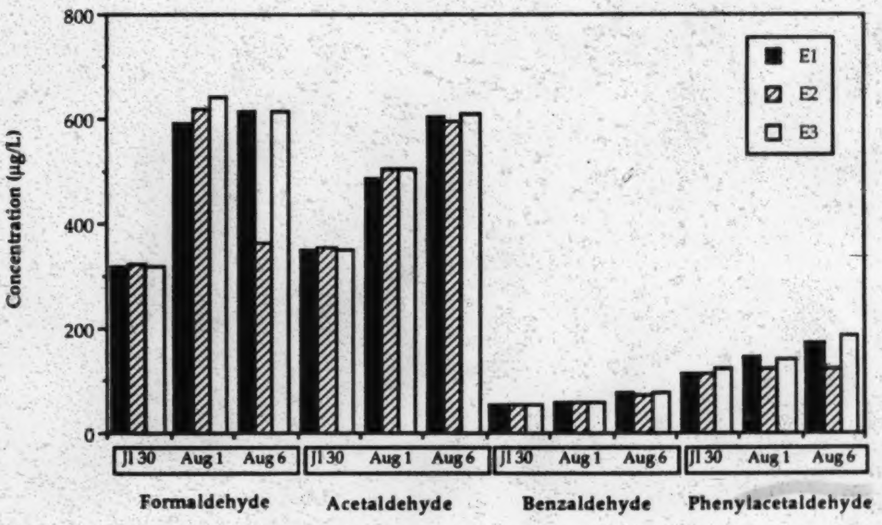


Figure 6.6 Aldehyde Analysis for Pool I-E. Example of Homogeneous Pool Profile on a Single Day Combined with Seasonal Profile. (See Figure 4.2 for Sampling Locations)

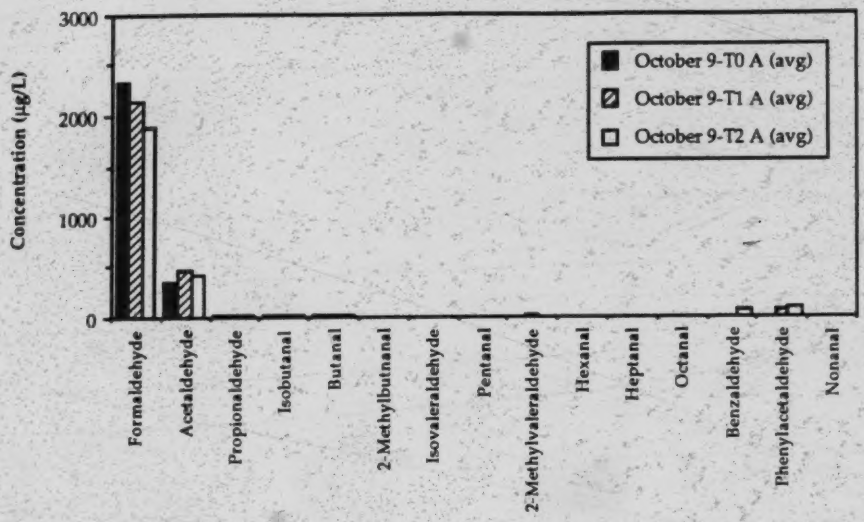


Figure 6.7 Aldehyde Time Profile for Pool I-A on October 9, 1990. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h Sampling Intervals.

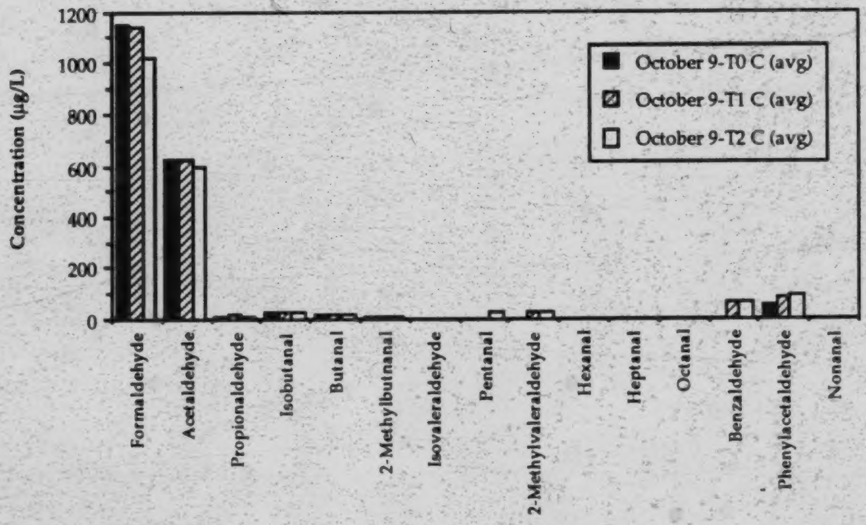


Figure 6.8 Aldehyde Time Profile for Pool I-C on October 9, 1990. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h Sampling Intervals.

In the second phase, levels of 1000 to 3000 µg/L of formaldehyde were present in several pools, while Pool I-B remains the cleanest pool again, with respect to aldehydes. These remarks are valid for both days of sampling (see Figure 6.9). Also noteworthy was that on November 29, 1990 Pool I-E did not present the worst level of formaldehyde. Both Pool I-A and Pool I-C and D exceeded Pool I-E. This observation is illustrated in Figure 6.10. Note that the figure shows the results in the late part of the day (sampling T2) but the observation is valid throughout the day.

The time profiles are as follows: acetaldehyde has a tendency to reach a peak during the middle of the day in all swimming pools, while formaldehyde has a mixed tendency of remaining fairly constant or decreasing slightly in all pools except in Pool I-E. There it peaks during the middle of the day similar to acetaldehyde. These latter time profiles were observed on October 9, 1990. They are different on November 29, 1990.

For November 29, 1990 samples, a much lower number of aldehydes were found. Only 3 aldehydes out of 15 were identified by retention times, even after further standard analysis for retention time matching was performed to ensure that the difference was not due to a gas chromatograph artifact. Again acetaldehyde and formaldehyde were the dominant aldehydes by a factor of 20 to 250, respectively. The time profiles were as follows: both formaldehyde and acetaldehyde usually start at their highest concentration at the beginning of the day, decreasing until mid-day only to remain constant or come back up slightly, but usually not as high as in the morning. In Pool I-E both predominant aldehydes are found in higher levels at night than in the morning after decreasing slightly during the day.

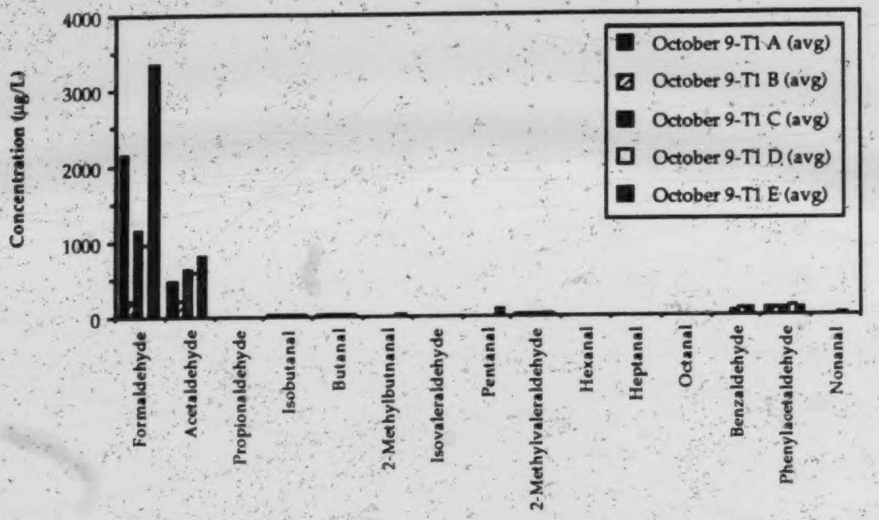


Figure 6.9 Aldehyde Analysis for Facility I on October 9, 1990. Showing Widespread Range of Concentration.

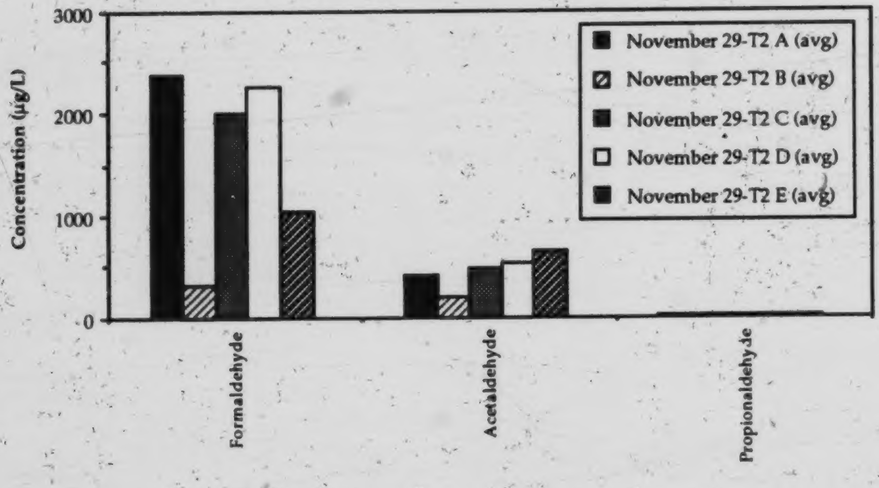


Figure 6.10 Aldehyde Analysis for Facility I on November 29, 1990. Showing the Reduced Variety of Aldehydes Found and Higher Formaldehyde Concentration in Pool A, C and D.

Pool II also showed, that acetaldehyde and formaldehyde were the prevailing aldehydes respectively, with the exception that formaldehyde was higher than acetaldehyde in one of the two hot tubs at the site, Pool II-χ (see Figures 4.4 to 4.6). Again benzaldehyde and phenylacetaldehyde are the higher molecular weight aldehydes that can be found in levels of 1/2 to 1/3 the prevailing low molecular weight aldehydes mentioned earlier (refer to Figures 6.11 and 6.12). While in the other cases, a ratio of 6 to 40 times less is observed, with some small noticeable exception in the hot tubs where isobutyraldehyde, isovaleraldehyde, pentanal and heptanal are somewhat in higher levels then the levels found in pools heated below 30°C.

The pool profile on July 7, 1990 was consistent with the prior observation, in that the concentration of aldehydes sampled at different locations, in a given tank, were fairly homogeneous (Figure 6.12). Subsequent sampling performed at the site resulted in individual sampling locations being mixed together prior to aldehyde analysis. Another observation made on the preservation-delay study still holds very well at Pool II, with the exception of pentanal and heptanal for which deviations of 100% and 57% were observed respectively in Pool II-χ only. The two hot tubs, Pool II-χ and Pool II-δ were sampled in duplicate and samples were preserved differently according to the 1 h and immediately before analysis (IBA) S_2O_3 addition.

Seasonal pool profiles are consistent with earlier observations, while daily time profile are not as obvious as showed in Figures 6.15 and 6.16. Summer sampling (Figures 6.11 to 6.14) showed more variety of aldehydes (8 to 10 aldehydes identified), while the Fall sampling presented only formaldehyde and acetaldehyde. The two hot tubs usually presented only slightly higher concentrations of total aldehydes than the other pools at the facility (summer or fall), while no strikingly higher concentrations were observed. The total aldehydes concentration from Pool II were generally lower than at Pool I; less than 400 μg/L in comparison with up to 3000 μg/L.

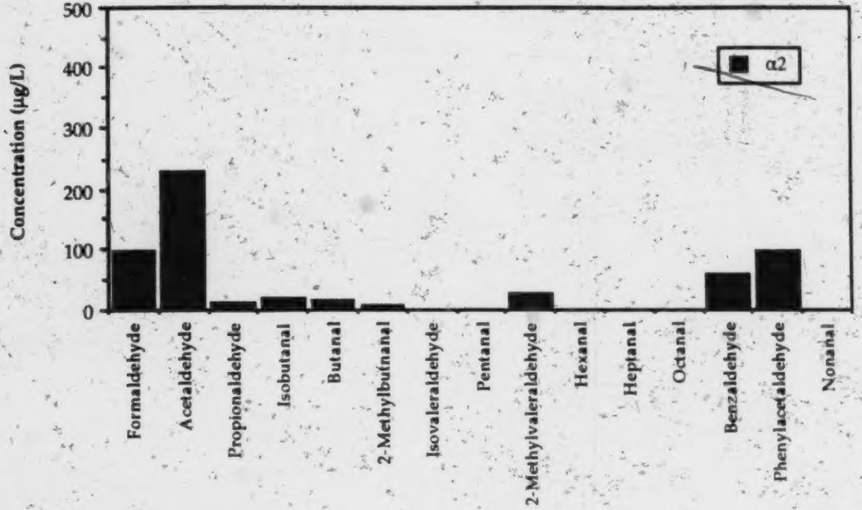


Figure 6.11 Aldehyde Analysis for Pool II-α on July 7, 1990.

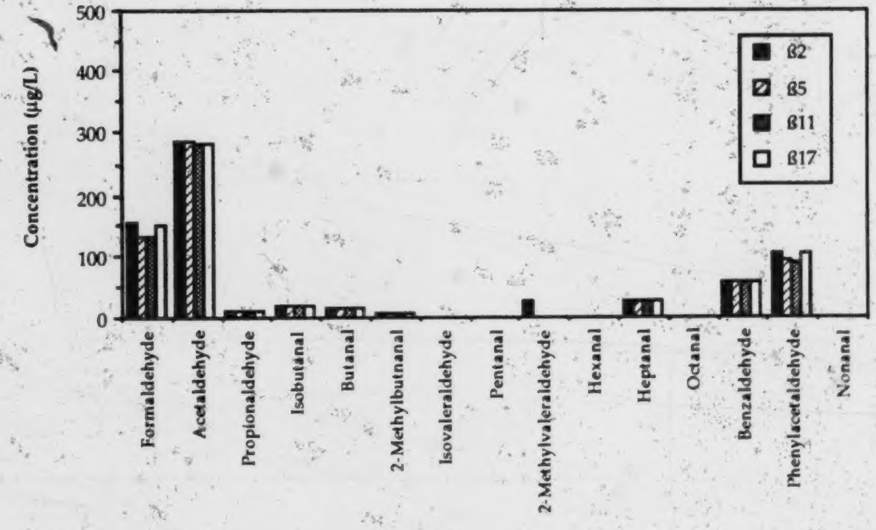


Figure 6.12 Aldehyde Analysis for Pool II-β on July 7, 1990.

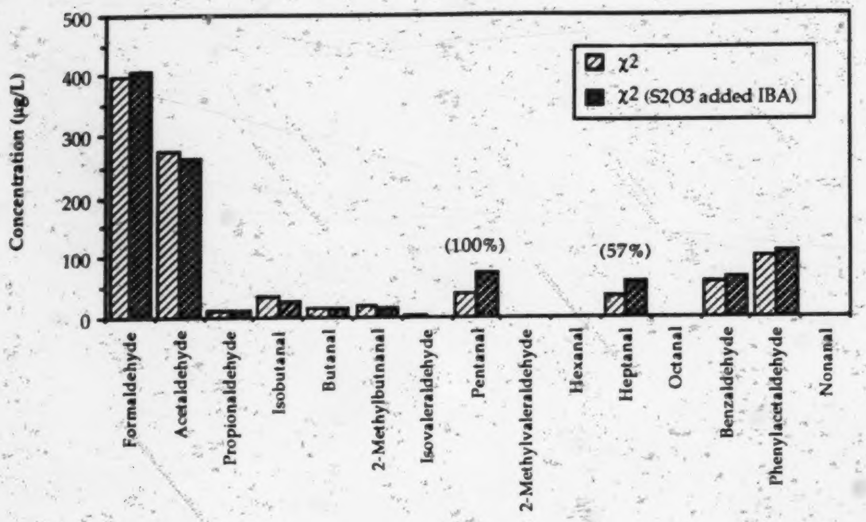


Figure 6.13 Aldehyde Analysis for Pool II-χ on July 7,1990. Study Comparing Preservation Treatment with Sodium Thiosulfate (S_2O_3). The Percentage Indicate the Worst Deviations Obtained Between the Two Treatments.

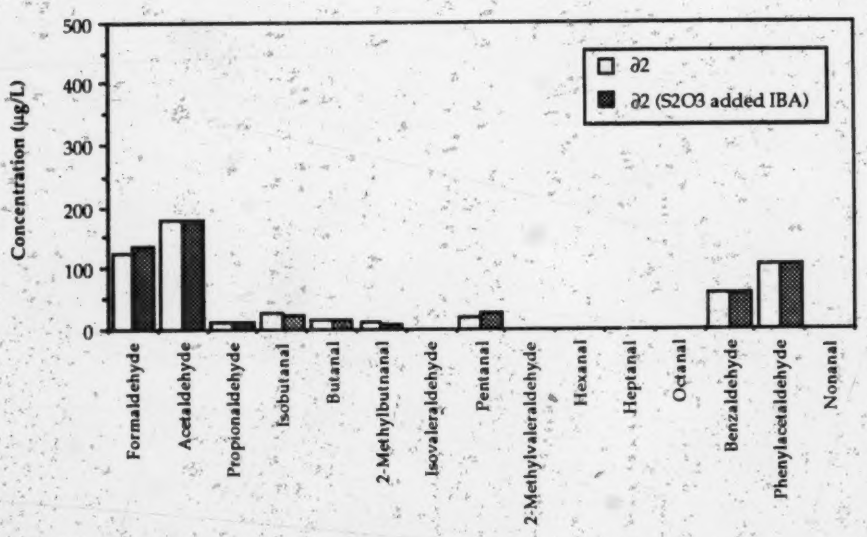


Figure 6.14 Aldehyde Analysis for Pool I-δ on July 7,1990. Study Comparing Preservation Treatment with Sodium Thiosulfate (S_2O_3).

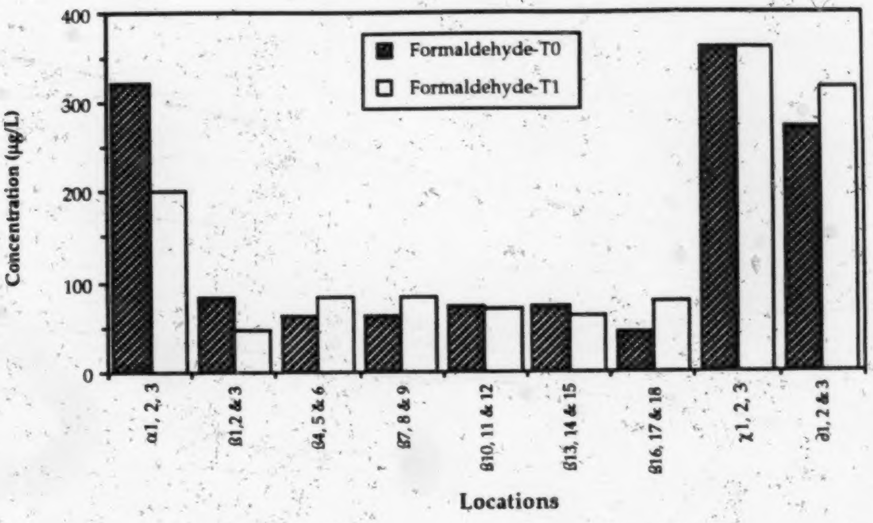


Figure 6.15 Formaldehyde Pool β Profile and Daily Pools Profile at Facility II on December 12, 1990. T0 and T1 correspond to 0 h and 4 h Sampling Intervals. (See Figure 4.5 for Sampling Locations)

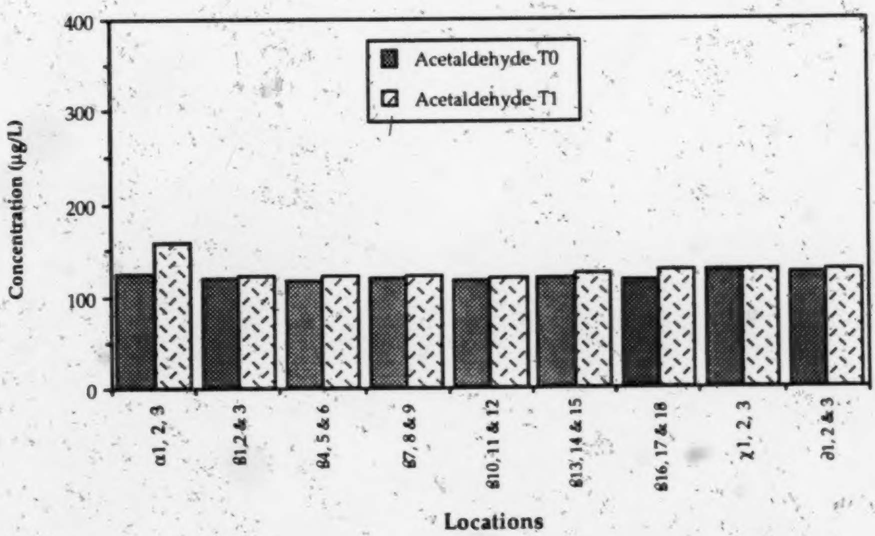


Figure 6.16 Acetaldehyde Pool β Profile and Daily Pools Profile at Facility II on December 12, 1990. T0 and T1 correspond to 0 h and 4 h Sampling Intervals. (See Figure 4.5 for Sampling Locations)

Pool III was sampled on July 5, 1990 and December 5, 1990. The summer sample again presented the highest number of aldehydes identified by retention time. Acetaldehyde and formaldehyde were the prevailing aldehydes, while benzaldehyde and phenylacetaldehyde were the two higher molecular weight aldehydes observed in slightly higher concentration than their counterparts with a ratio of 2 to 3 less in comparison with the lower molecular weight aldehydes. Figure 6.17 shows the results obtained for the Summer sampling performed on July 5, 1990.

In the first phase of the sampling program a preservation study was carried through with samples from each pool sections as identified by the schematic for Facility III in Figures 4.7 and 4.8. Facility III is the farthest from the University of Alberta and analysis delay is the most important. As can be seen in Figure 6.18 there was no difference reported between the different samples preserved as addition of S_2O_3 within 1 h of sampling and S_2O_3 added immediately before analysis (IBA).

Only formaldehyde was observed consistently during the fall sampling. The daily time profile shows a tendency of decreasing concentration throughout the day from a morning high. A slight pool profile was also observed in respect to formaldehyde in both the summer and the fall, while acetaldehyde remains fairly homogeneous throughout the pool in the summer. Pool III, consists of only one tank with two bulkheads forming an artificial separation. The bulkheads are moved on a regular basis during the week according to the different swimming programs being run.

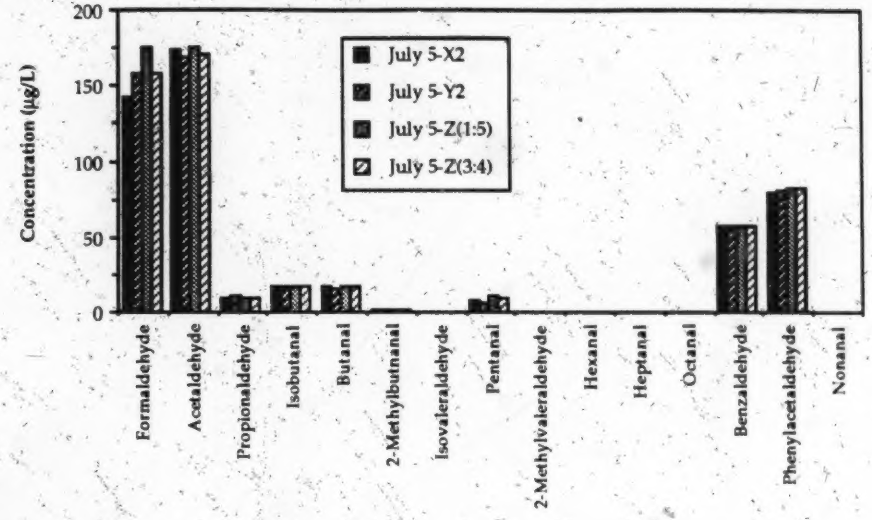


Figure 6.17 Aldehyde Analysis for Facility III on July 5, 1990.

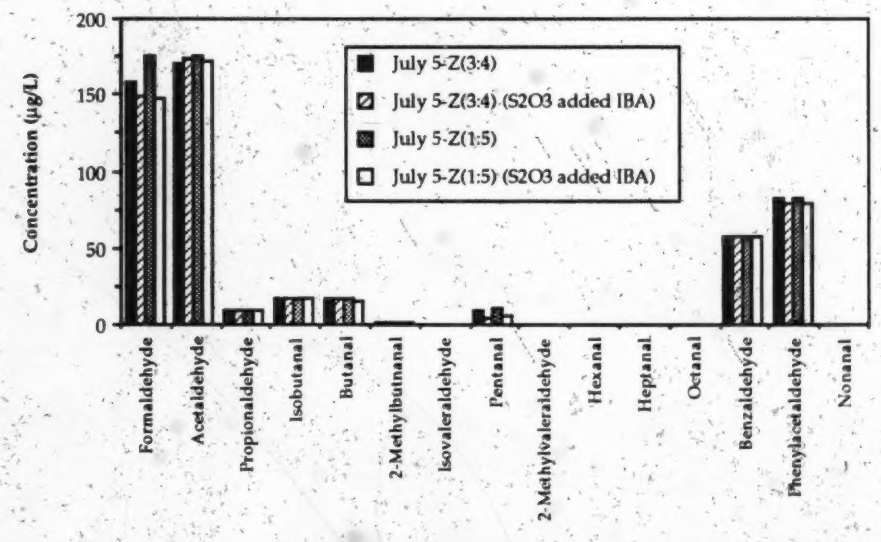


Figure 6.18 Aldehyde Analysis for Pool III-Z on July 5, 1990. Study Comparing Preservation Treatment with Sodium Thiosulfate (S2O3).

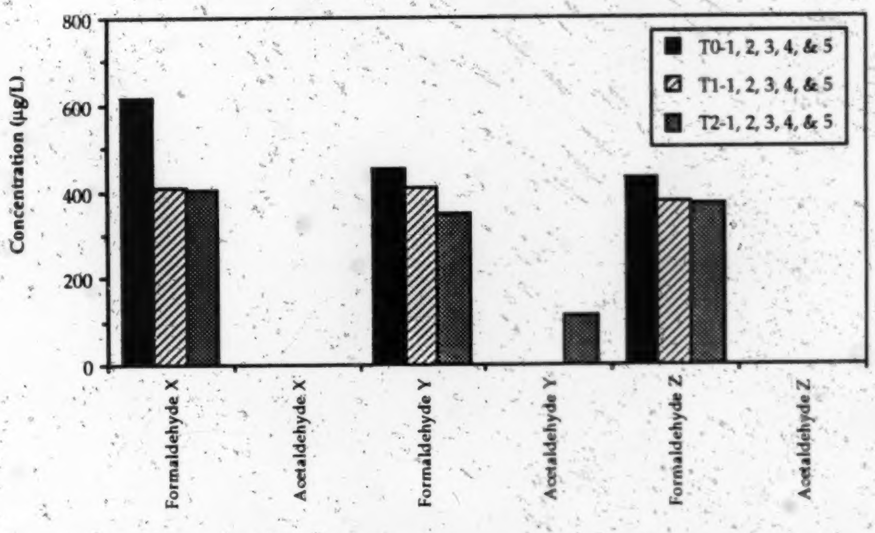


Figure 6.19 Aldehyde Analysis for Composite Samples (1, 2, 3, 4 & 5) for Each Sections (X, Y and Z) at Facility III on December 5, 1990. Study Showing Daily Profile. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h Sampling Intervals.

6.1.2 Chlorine Speciation

Chlorine profiles are shown in Figures 6.20 and 6.21 for July 26 and July 30, 1990 from Pool I-A. These illustrate the differences between swimming pools and give an example of individual swimming pool profile with respect to the 3 different sampling locations in each tank. Because the different sampling days present the same basic results, only the two initial days are presented with figures. More detailed results can be found in tabular form in Appendix D2.2.

As can be seen from Figure 6.20, the different swimming pools present different levels of free available chlorine (FAC), chloramines, combined residual and total residual. On the other hand, individual swimming pools present homogeneous levels with respect to different sampling locations. A swimming pool profile is observed on a daily basis and on a seasonal basis. This would most certainly agree with our expectation of dependency on bather load on a daily and seasonal basis, respectively.

Pool I generally shows good agreement with Alberta Regulation 247/85, with respect to FAC minimal amounts of 0.5 ppm in pools under 30°C and 1.0 ppm in pools over 30°C. Although, it appears to have greater difficulty in controlling the minimal FAC level in Pool I-E. This pool is heated above 30°C and should maintain a minimum FAC level of 1.0 ppm. The required level was never observed on any of the 6 days of sampling performed at that facility. The best results were observed during the months of July, August and November with levels of 0.4 to almost 1 ppm, and the worst results were observed on October 9, 1990, at levels of 0.1 to 0.2 ppm.

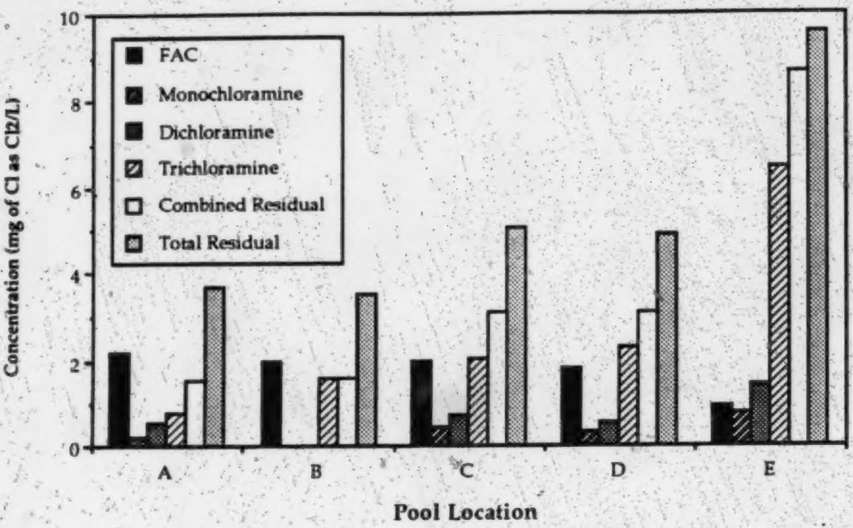


Figure 6.20 Chlorine Profile for Each Individual Tank at Facility I on July 26, 1990. (See Figure 4.2 for Sampling Locations).

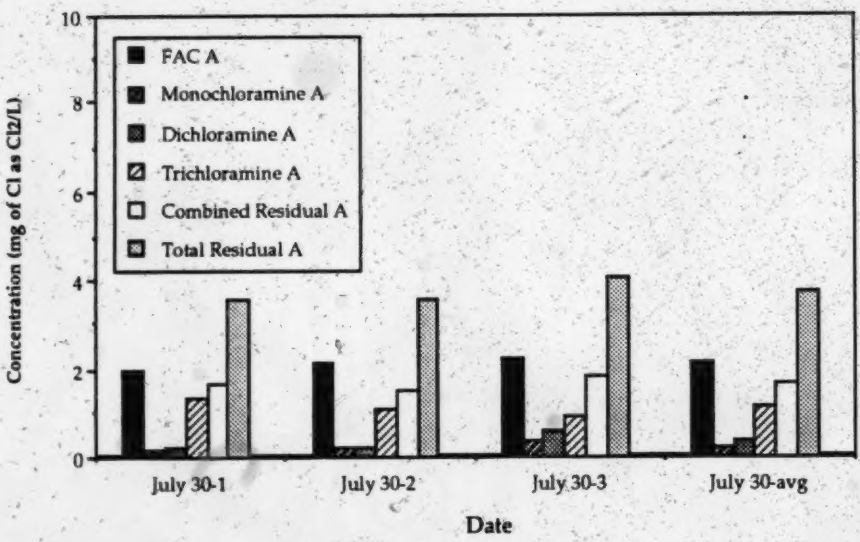


Figure 6.21 Chlorine Profile for Pool I-A on July 30, 1990. Comparison Between the Different Sampling Locations. (See Figure 4.2 for Sampling Locations)

The regulation also stipulates a maximum permissible amount for a combined chlorine residual of 1.0 ppm. This value was met only in Pool I-B on all 6 sampling days. The remaining swimming pools at the facility were found to be in excess by 25% to as much as 650% (August 6, 1990 Pool I-E). The regulated maximum allowable limit for combined residual is important in order to achieve swimmers comfort. The inorganic chloramines constitute what is called the "bound effective chlorine". In swimming pool waters this level has been proposed as a measure of the degree to which an irritation of the mucous membrane of swimmers will occur (Lahl et al. 1981).

The method of analysis used, the DPD titrimetric FAS method, is plagued by interferences of the chloronitrogenous organic kind (Standard Methods 1989, Jensen and Johnson 1990). These species constitute, none the less, a valid combined residual reading with the added negative features of providing essentially no germicidal action (Isaac and Morris 1980) and potentially additional toxicity to the bathing waters. At any rate, limiting the formation of these organic chloramines can only be beneficial with respect to the swimmers comfort.

The chloronitrogenous organic species are obtained in the additional titration step performed to determine trichloramine levels in the DPD titrimetric method. When this additional step is performed the addition of the necessary chemical (phosphate buffer, DPD reagent and Potassium iodide) for the speciation in the previous determination of FAC, mono and dichloramines is inverted in order to influence the reaction to occur faster and favour the slower reacting species in presence of potassium iodide (KI) and absence of phosphate buffer (pH=7) and DPD reagent, which in turn are added just before the titration is performed (within a few seconds). Unfortunately, the slower chloronitrogenous organic species also react at this stage and a specific reading of trichloramine is impossible. This leaves the FAC, monochloramine and dichloramine speciation steps essentially unaffected, since their rates of reaction are faster under the pre-buffered conditions under which they are determined (Jensen and Johnson 1990). Still by adding only monochloramine and dichloramine levels, Pool I-E is over the maximum allowable limit, while Pool I-C and Pool I-D are very close to the maximal permissible limit during the 4 summer samplings. Only Pool I-A and Pool I-B would meet the regulations throughout the sampling period covering July, August, October and November.

The values reported as trichloramine (NCl_3) in the Tables in the Appendix section, as well as the values in the Figures include the organic chloramines. The DPD titrimetric ferrous method made impossible the differentiation of the inorganic chloramines from the organic chloramines, as earlier explained. To provide additional information about the organic chloramines a second method was used in the speciation of the different chlorine species, the amperometric titration method. This method was also used to provide information about degradation rate of the FAC and other chlorine species. These experiments were performed on samples from the method development swimming pool at the University of Alberta. This allowed to perform the analysis without delay with respect to transportation.

Figures 6.22 to 6.29 show the broken-up results for the chlorine species identified by the DPD titrimetric method and the amperometric titration method. Two experiments were performed with respect to low and high level of trichloramine, the potentially contaminated step. FAC showed an overall decreasing tendency, with observed decrease of 29% (DPD) and 53% (amperometric) in the first experiment. The combined residual, resulting from the sum of the three individual species: mono-, di- and trichloramine (definitely including the organic chloramines) showed a mixed behaviour, no degradation could be assessed.

The second experiment was attempted, in order to represent the situation when trichloramine levels occurred in higher concentration. Again, FAC results showed a decreasing tendency. This time resulting in 38% (DPD) and 40% (amperometric) decrease. No defined behaviour could be established for the combined residual species.

In both experiments, the bulk of the FAC degradation occurred within 24 h, with a slower subsequent degradation after 24 h. Also, the results obtained from the two methods, for all the species, were different when comparing a given sample at any specific time. As a general comment, the FAC levels would compare fairly well between the two different methods throughout the experiments. But the combined residual levels obtained from the amperometric method would be higher then the results obtained with the DPD method.

As discussed in Standard Methods (APHA et al. 1989) and by Jensen and Johnson (1990 and 1990), neither methods would be able to differentiate inorganic chloramines from organic chloramines. As a result, the DPD titrimetric method was retained for use in this study, because of its simplicity and relative precision in recording titrant volume added. It is relatively simple to read the volume within 1% precision (Joller and Carpenter 1983). In comparison, potentiometric alternative provide a precision of about 5% and are limited by the logarithmic (Nernstian) response of the electrode (Jolley and Carpenter 1983).

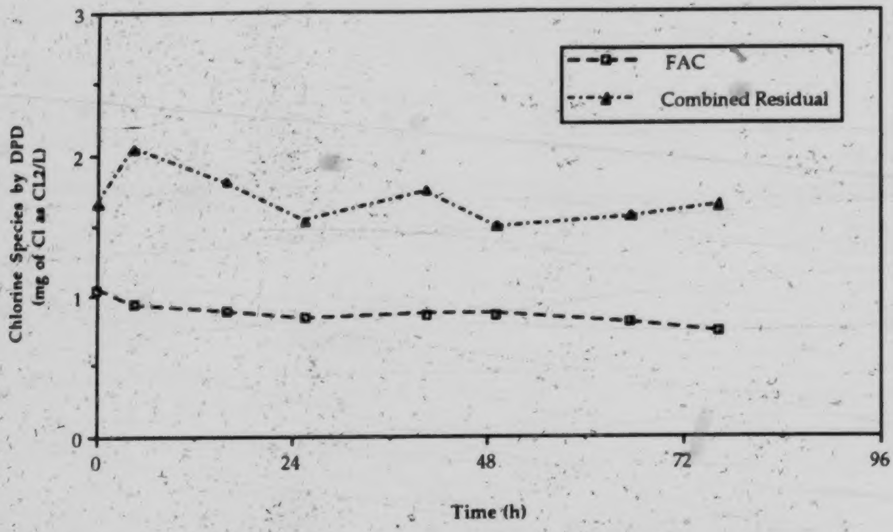


Figure 6.22 Study of Degradation of FAC and Combined Residual as Detected by the DPD Method. First Experiment Low Level of NCl_3.

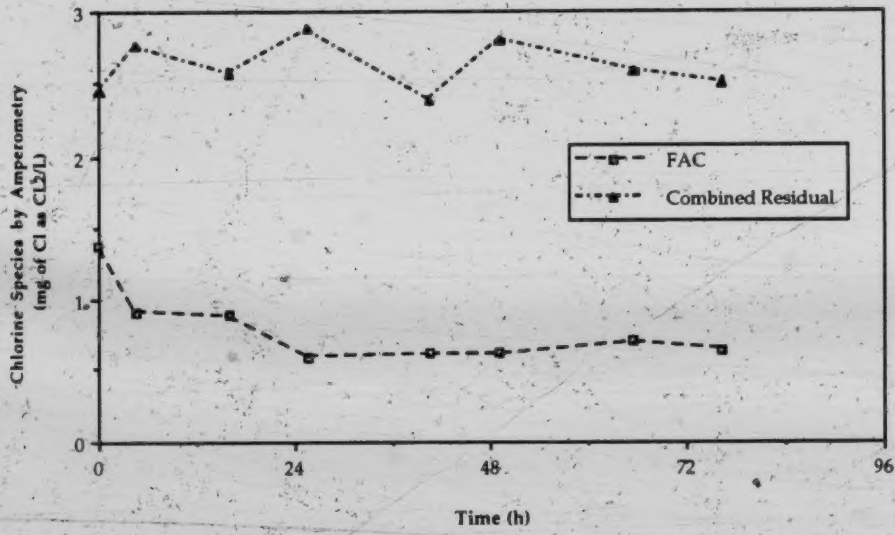


Figure 6.23 Study of Degradation of FAC and Combined Residual as Detected by the Amperometric Method. First Experiment Low Level of NCl_3.

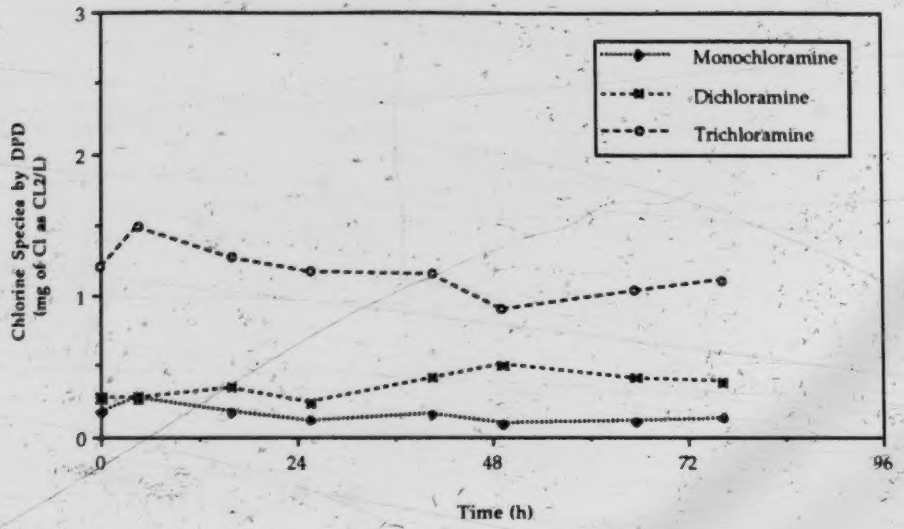


Figure 6.24 Study of Degradation of Mono-, Di-, and Trichloramines as Detected by the DPD Method. First Experiment Low Level of NCl3.

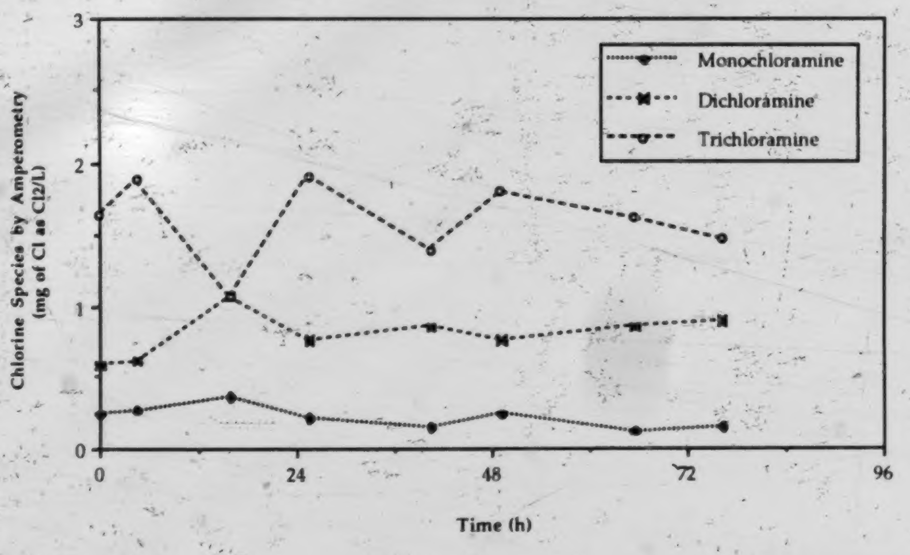


Figure 6.25 Study of Degradation of Mono-, Di-, and Trichloramines as Detected by the Amperometric Method. First Experiment Low Level of NCl_3.

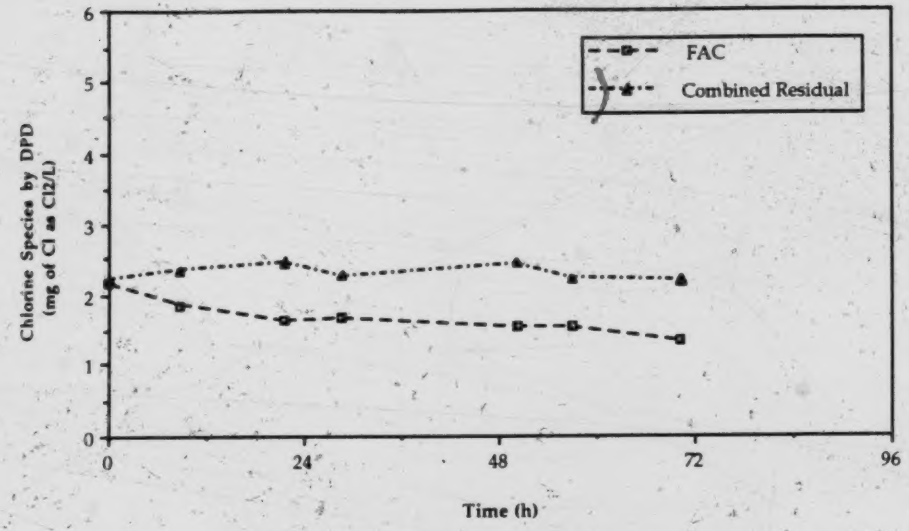


Figure 6.26 Study of Degradation of FAC and Combined Residual as Detected by the DPD Method. Second Experiment High Level of NCl3.

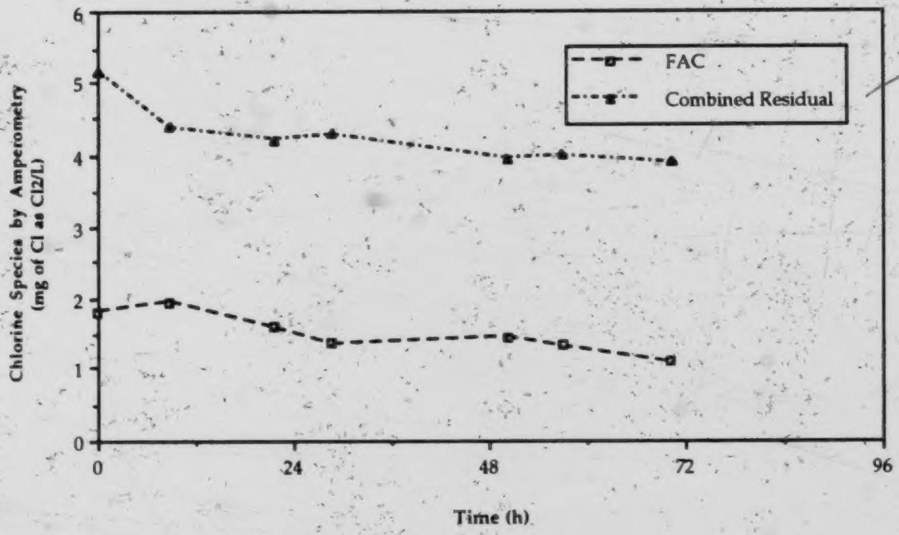


Figure 6.27 Study of Degradation of FAC and Combined Residual as Detected by the Amperometric Method. Second Experiment High Level of NCl_3.

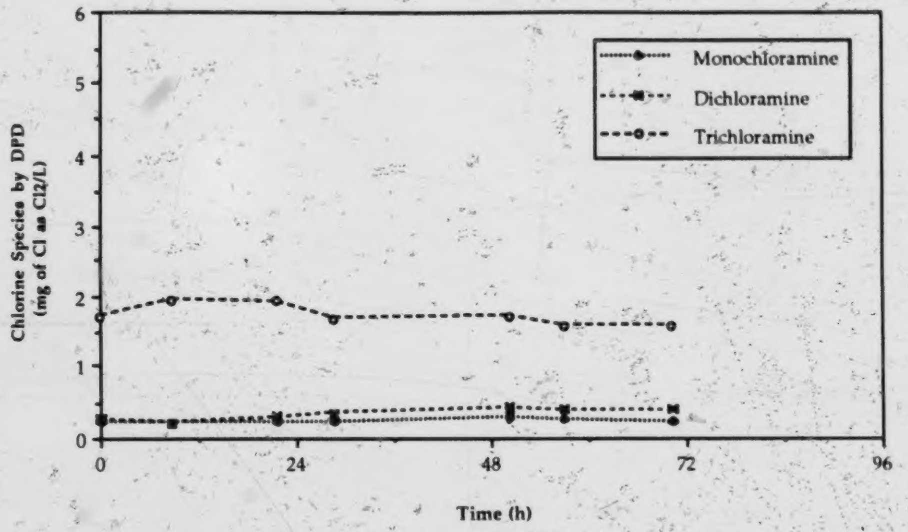


Figure 6.28 Study of Degradation of Mono-, Di-, and Trichloramines as Detected by the DPD Method. Second Experiment High Level of NCl3.

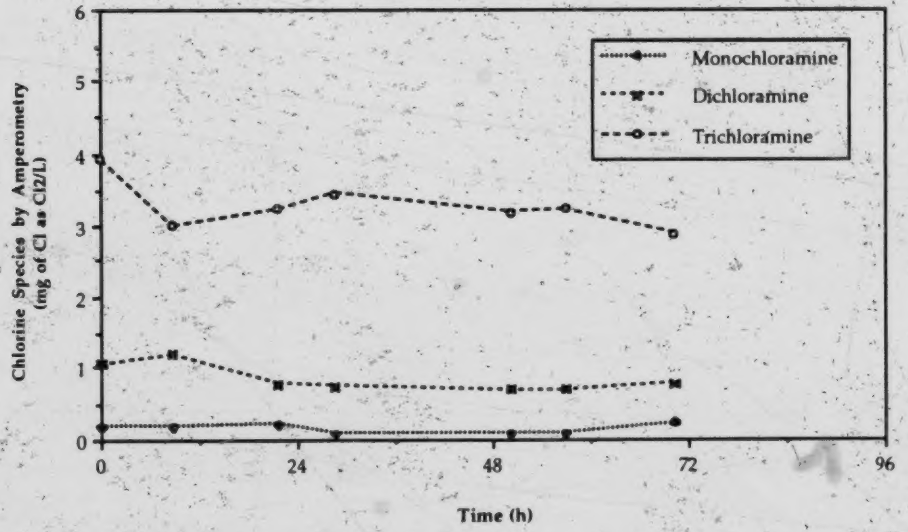


Figure 6.29 Study of Degradation of Mono-, Di-, and Trichloramines as Detected by the Amperometric Method. Second Experiment High Level of NCl_3.

Pool II shows a similar profile, in that concentrations in a given tank at a given time were fairly homogeneous. Daily and seasonal time profiles were again observed. Again regulations are difficult to meet in the case of pools heated over 30°C, Pool II-χ and Pool II-δ for both FAC and combined residual. The combined residual, if only monochloramine and dichloramine levels were used, would be met in the fall sampling for all pools with the exception of the two hot tubs, while the summer sampling would not meet the regulations in any case. Using the separate added step for trichloramine and the added interferences, organic nitrogenous compounds, none of the pools would meet the maximal allowable combined residual level of 1.0 ppm, at any time. Combined residual levels would be in excess by 200% to 630%. Figures 6.30 to 6.32 show the results and trends discussed above.

Pool III always met the FAC minimal regulated level in both the summer and fall sampling program. There was a tendency for the FAC level to decrease during the day. If only, monochloramine and dichloramine were used for combined residual, the maximal permissible combined residual level of 1.0 ppm would also be met at all times. But, if the trichloramine were also used, the level of combined residual would exceed the allowable limit by 5% to 97% (see Figure 6.33).

The level of combined residual found at Pool III represented the lowest level of all three Facilities participating in this study. As a general profile for Pool III, considering the worst case, the combined residual level represented less than 50% of the total residual. In comparison, Pool I on July 26, 1990 (see Figure 6.20) presented levels that were of a similar order when comparing pools with similar temperatures, while Pool I-E which was maintained at a higher temperature showed that 90% of the total result was

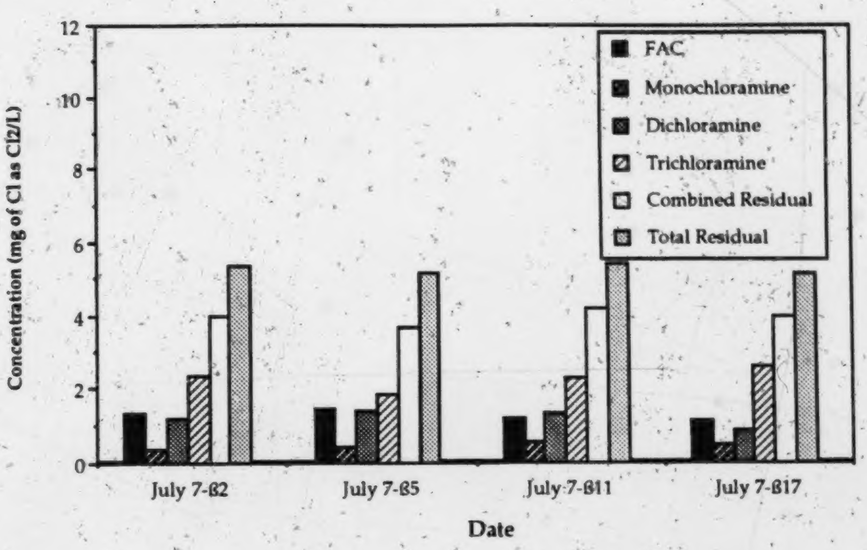


Figure 6.30 Chlorine Profile for Pool II-β on July 7, 1990. Comparison Between the Different Sampling Locations. (See Figure 4.5 for Sampling Locations).

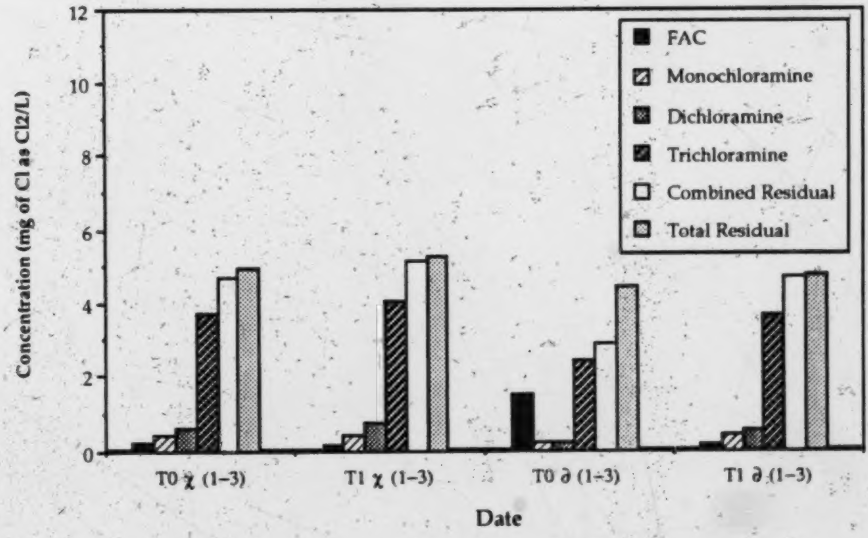


Figure 6.31 Chlorine Profile for Pools II-χ and δ on December 12, 1990. Study of Daily Profiles. T0 and T1 Correspond to 0 h and 4 h Sampling Intervals.

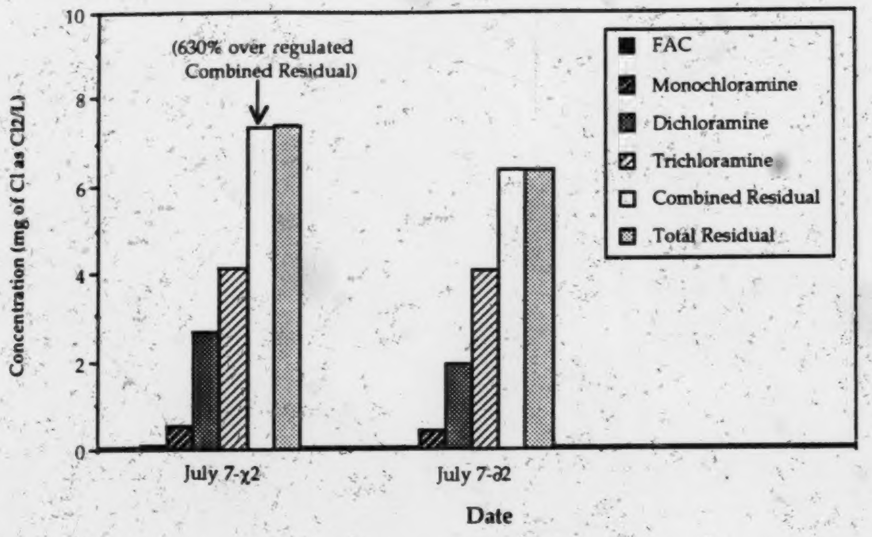


Figure 6.32 Chlorine Profile for Pools II-χ and δ on December 12, 1990. Showing Levels of Combined Residual.

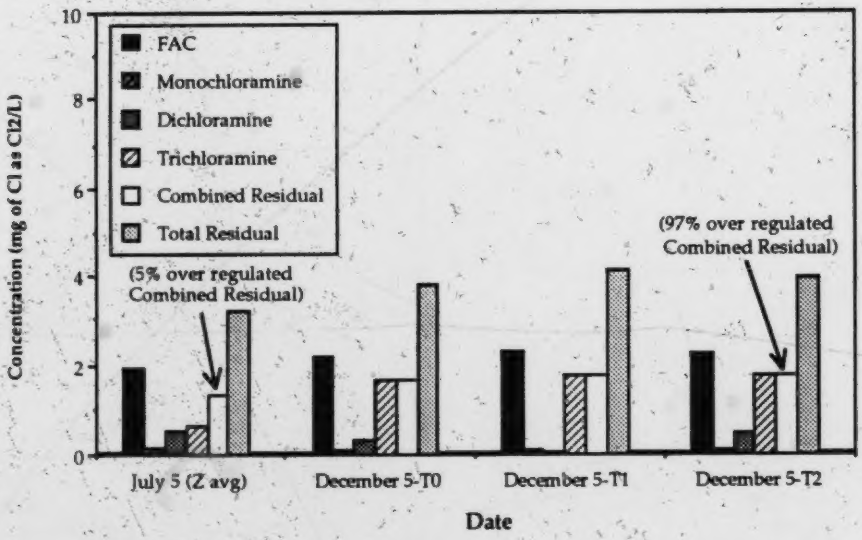


Figure 6.33 Chlorine Profile for Pool III-Z on July 5 and December 5, 1990. Showing Levels of Combined Residual and Daily Profile. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h Sampling Intervals.

combined. Pool II shows that 60 to 80% of the total residual was combined and the two hot tubs at this site showed that 95% of the total residual was combined.

6.1.3 Trihalomethanes

Trihalomethane swimming pool profiles can be found in Figures 6.34 and 6.35 for July 26, 1990 and July 30, 1990 samples from Pool I. Averages of pool profile were used to report July 30, 1990 data since the sampling location did not affect the results. More detailed results can be found in tabular form in Appendix D3.4.

As shown in the trihalomethane (THM) individual pool profiles, chloroform and dibromochloromethane were the predominant species found in pool water. Bromoform was never observed on any of the sampling dates at any of the 3 sites and was left out altogether for ease of reporting. Levels of all three THMs found were very consistent throughout the sampling program on the different days and it was difficult to consider a daily pool profile, with the exception of very strong peaking effects. Such effects were observed for the chloroform and dibromochloromethane only.

Initially the very high values were studied to determine if they were artifacts of the gas chromatographic analysis, but after careful consideration of the chromatograms in replicate analyses from different vials, a randomized order of analysis eliminated analytical artifacts as an explanation for the high values. The peaks remained for fairly short times because between successive samplings the levels usually dropped back to their previous average observed level. No parallel with bather load could be established because the number of bathers reported at the time of sampling was low. However, the number of bathers reported was for the 15 to 20 min that the sampling was actively

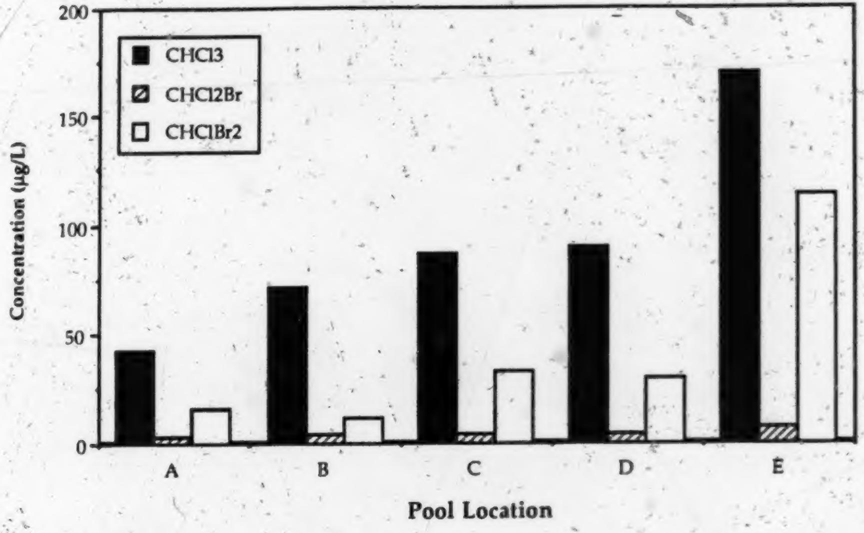


Figure 6.34 THMs Profile for Facility I on July 26, 1990.

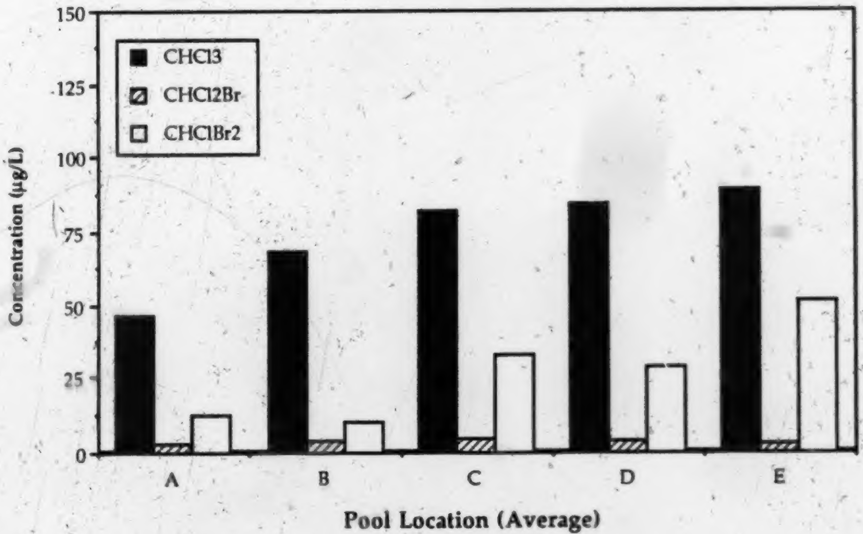


Figure 6.35 THMs Profile for Facility I on July 30, 1990. Results Based on Average of the Different Sampling Locations.

taking place. There could have very well been a class just finishing prior to the sampling taking place, while the reported number was zero.

Pool II shows chloroform and dibromochloromethane as the prevailing THMs during the summer sampling, while only chloroform appears in any interesting level during the fall sampling. The levels observed are similar to Pool I, and again the heated pools have higher concentrations of the THMs in both seasons. There seems to be a slight daily pool profile with a tendency of finding decreasing levels of chloroform in the latter part of the day. In total, 18 different sampling locations were sampled in Pool II-β and were analyzed as 6 samples (3 were mixed together). Replicate analyses were performed and a good agreement of all 6 results at the two different sampling times during the day was found to be homogeneous throughout the pool with decreasing concentrations between the two sampling times.

Pool III has slightly lower THM concentrations than Pool I and Pool II, with chloroform and dibromochloromethane prevailing during the summer and chloroform during the winter. There was no appearance of a daily pool profile. A supplementary sample was analyzed on December 5, 1990, this sample was taken from the feed line from the filtration units providing water to the swimming pool. The difference in the average level of chloroform present in the pool (all sections combined) was only 11% less when compared with the feed line sample. The differences could most certainly be explained by volatilization of the compounds into the overlying atmosphere. Figures 6.38 and 6.39 show the results discussed above.

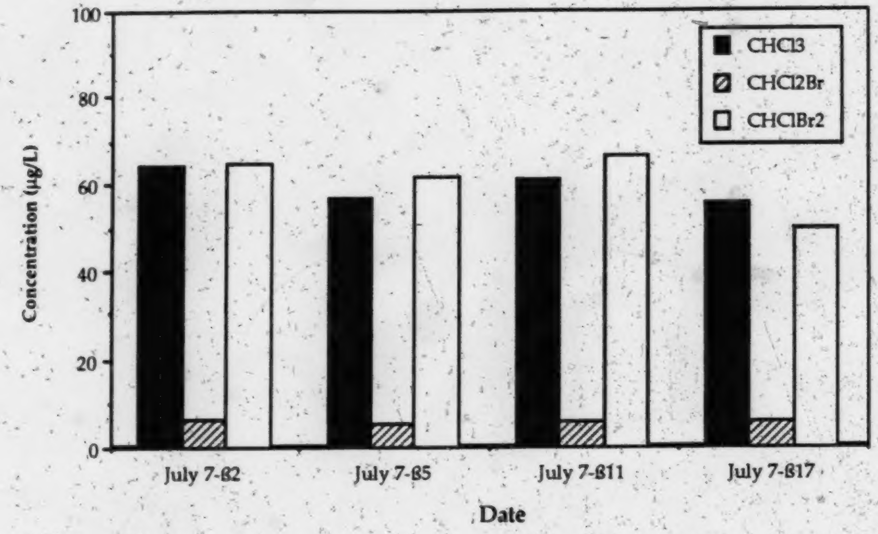


Figure 6.36 THMs Profile for Pool II-β on July 7, 1990. Results for Different Sampling Locations. (See Figure 4.5 for Sampling Locations).

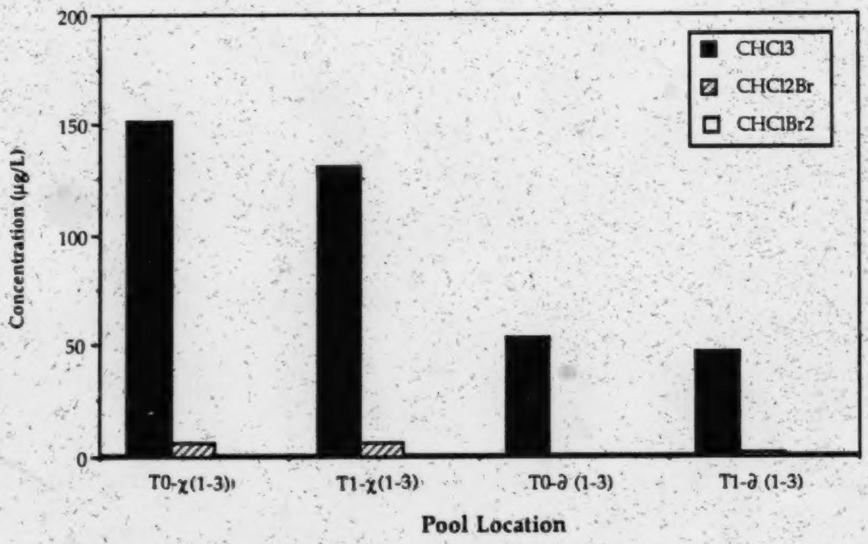


Figure 6.37 THMs Profile for Pools II-χ and δ on December 12, 1990. Study of Daily Profile. T0 and T1 Correspond to 0 h and 4 h Sampling Intervals.

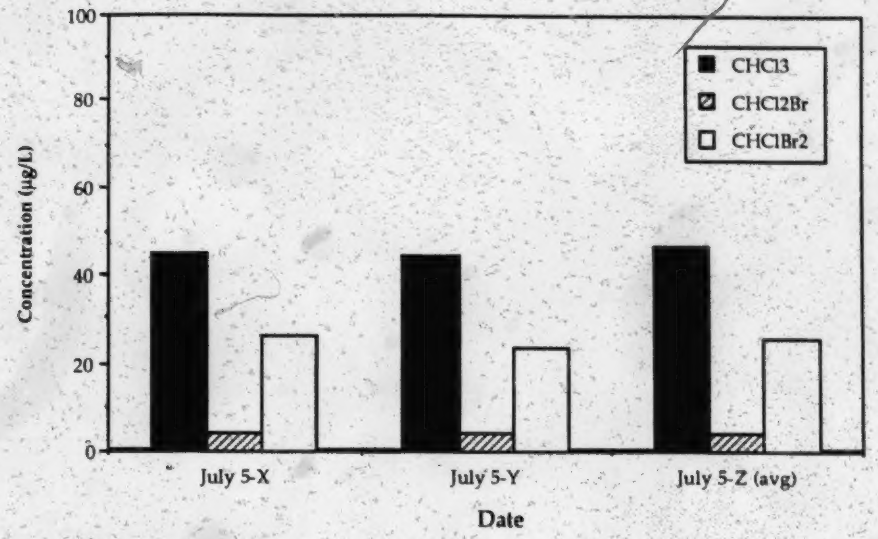


Figure 6.38 THMs Profile for Facility III on July 5, 1990. X, Y and Z Represent the Different Sections of the Pool Separated by Bulk-Heads. (See Figure 4.7).

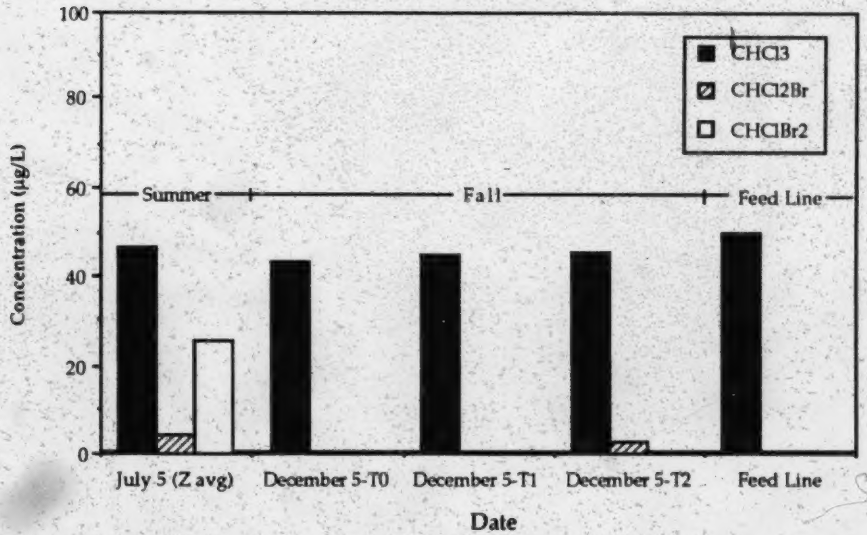


Figure 6.39 THMs Profile for Pool III-Z. Study Showing Seasonal Profile and Daily Profile. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h Sampling Intervals.

6.1.4 Total Kjeldahl Nitrogen

The total kjeldahl nitrogen (TKN) results do not show individual swimming pool profiles, or daily pool profiles. In fact, there was only a very small seasonal profile. Only Pool I-E showed notable differences between the summer and fall samplings (see Figure 6.40). This latter pool also had the highest levels of TKN, while Pool I-B was the cleanest with respect to TKN loading, throughout the summer and fall (see Figure 6.41).

Pool II summer samples were performed on 100 mL aliquots and no nitrogen was detected. As can be Seen on Figure 6.42, only χ showed some nitrogen in the summer. A modified protocol was then used for the samples in the later part of July and until completion of the sampling program at all pools. In the fall, analyses were performed on 500 mL aliquots, to provide results for Pool II-α and Pool II-β that were similar to the levels present in Pool I-A, Pool I-C and Pool I-D. The levels remain fairly constant during the day with only a very slight loss. Again the heated pools present the highest level, and a tendency to indicate decreasing levels during the day.

Pool III follows the same scenario as Pool II for the analysis procedure. Results for the fall season were very consistent throughout the pool, independent of the pool section. Because of the earlier observations about pool homogeneity with respect to sample locations, samples were mixed as per individual sections prior to analysis. Results showed in Figure 6.43 are based on mixed samples (e.g locations 1 to 5 for section X, X (1-5)). The additional sample from the feeding line from the filtration units yields the same TKN level as in the pool. There was no daily time profile. Results, in general, were lower than levels found in Pool I except for Pool I-B which

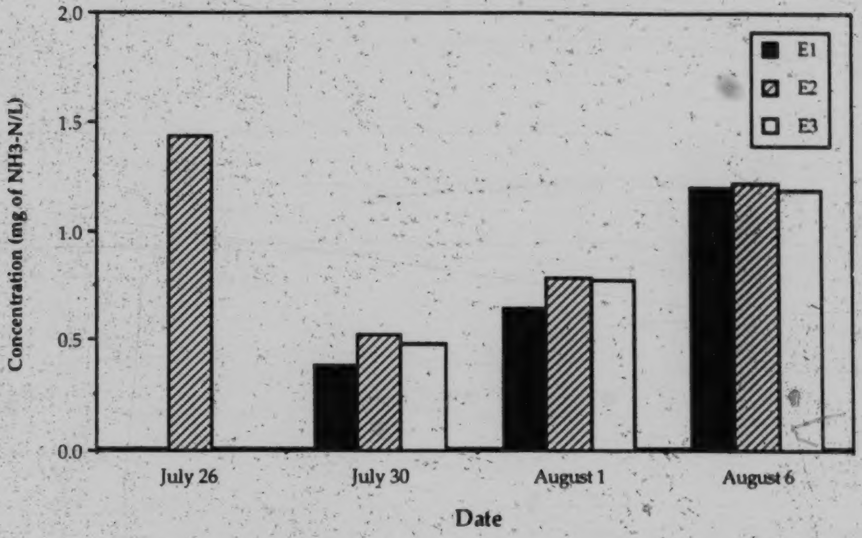


Figure 6.40 TKN Profile for the Summer Sampling at Pool I-E. Study Showing Seasonal Profile and Pool Profile with Respect to the Different Sampling Locations. (See Figure 4.2).

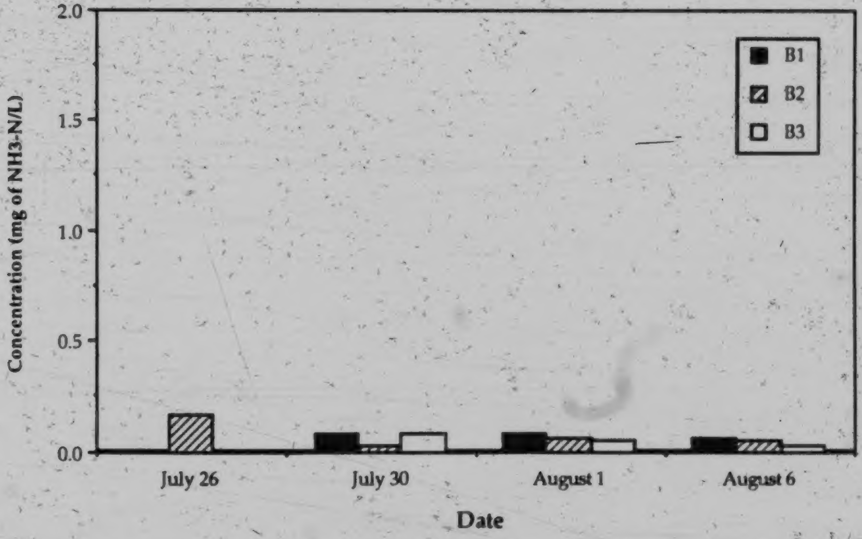


Figure 6.41 TKN Profile for the Summer Sampling at Pool I-B. Study Showing Seasonal Profile and Pool Profile with Respect to the Different Sampling Locations. (See Figure 4.2)

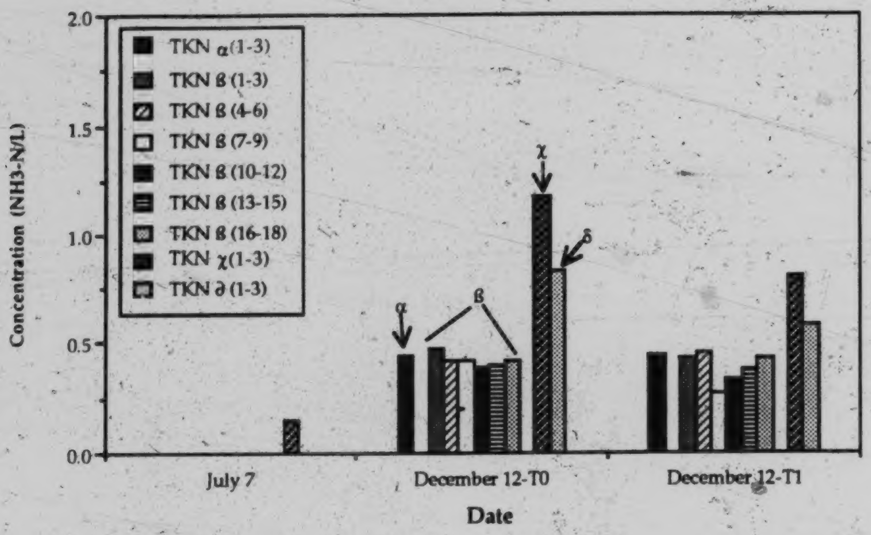


Figure 6.42 TKN Profile at Facility II. Study Showing Seasonal Profile, Pool Profile and Daily Profile. T0 and T1 Correspond to 0 h and 4 h Sampling Intervals. (See Figure 4.5 for Sampling Locations).

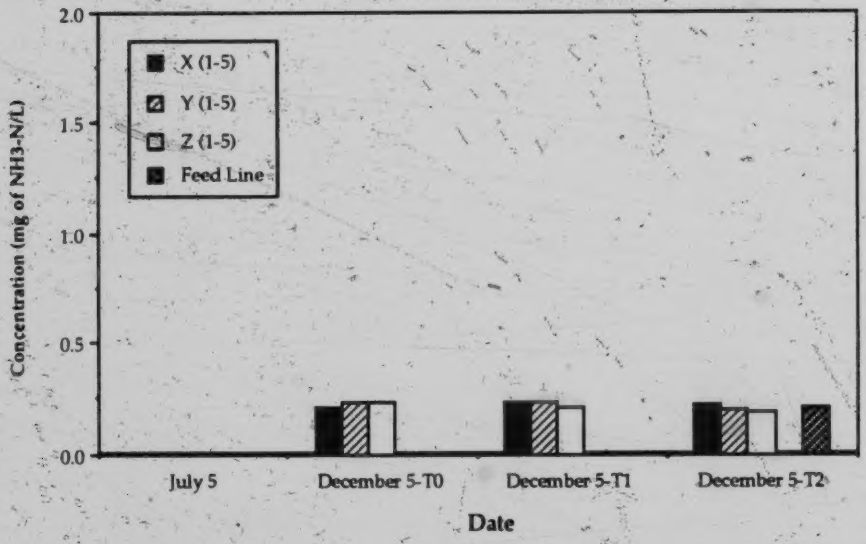


Figure 6.43 TKN Profile at Facility III. Study Showing Seasonal Profile, Pool Profile (Based on Different Sections) and Daily Profile. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h. (See Figure 4.7 for Sampling Location).

remained the cleanest with respect to TKN levels. Detailed results for the TKN analysis can be found in Appendix D4.2.

As reported in section 2.1.1.3, similar reaction mechanisms provide aldehydes and nitriles as disinfection by-products following chlorination of organically contaminated water. The formation of aldehydes should be correlated to TKN because of their formation from amino acids. As can be seen in Figure 6.44, results from the July 26, 1990 sampling at Facility I showed a correlation between the aldehyde levels and the total kjeldahl nitrogen (TKN) levels. The same trend was observed on all six days of sampling at Facility I. A more general plot (Figure 6.45) shows all six days of sampling and provides a correlation coefficient, R = 0.67 which is significant at the 1% level.

A similar trend was observed in Figure 6.46 which showed the aldehyde formation in respect with the total organic carbon (TOC) present. That is, formation of aldehydes as disinfection by-products depends on the availability of substrate as measured by the TOC (and TKN) levels. The correlation between TOC and TKN is showed in Figure 6.47. The correlation coefficient between TOC and TKN (R=0.975) is significant at the 1% level. This simply suggest that the organic contaminants (measured as TOC) in the water were dominated by amino acids, peptides and similar organic nitrogen compounds. These type of compounds would be shed from the bathers and measured as TKN.

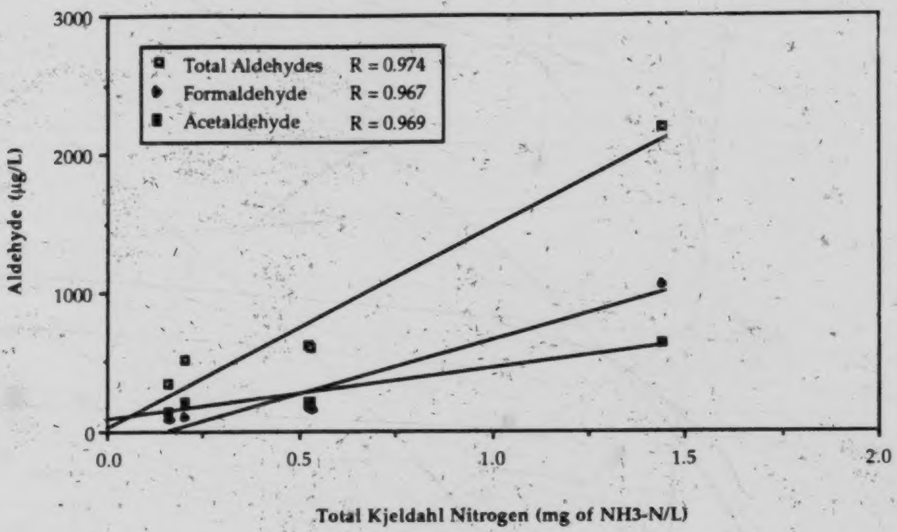


Figure 6.44 Correlation Between Total Aldehydes and TKN at Facility I on July 26, 1990.

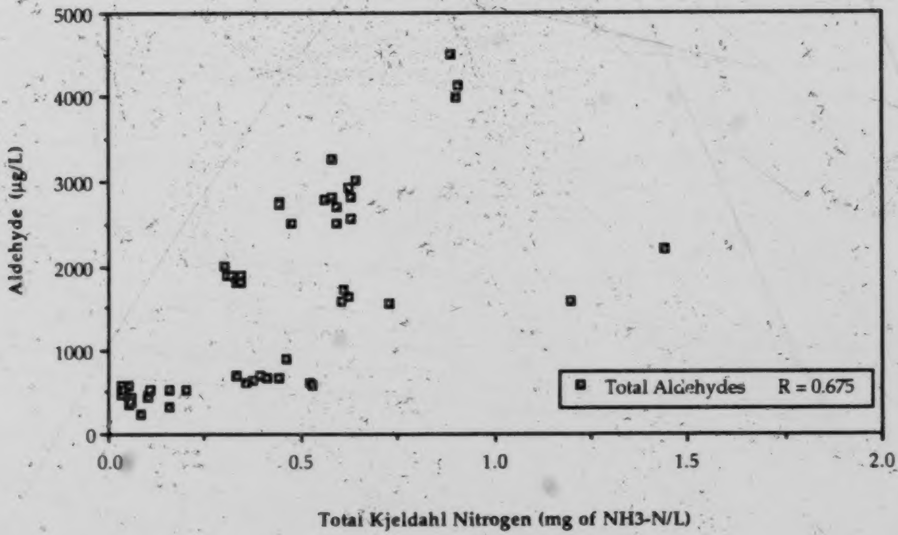


Figure 6.45 Correlation Between Total Aldehydes and TKN at Facility I. Data for all 6 Days of Sampling.

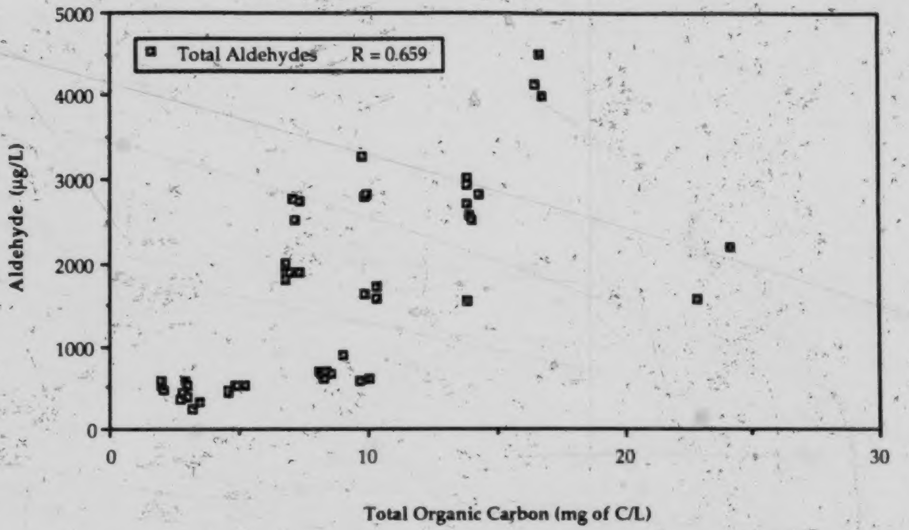


Figure 6.46 Correlation Between Total Aldehydes and TOC at Facility I. Data for all 6 Days of Sampling.

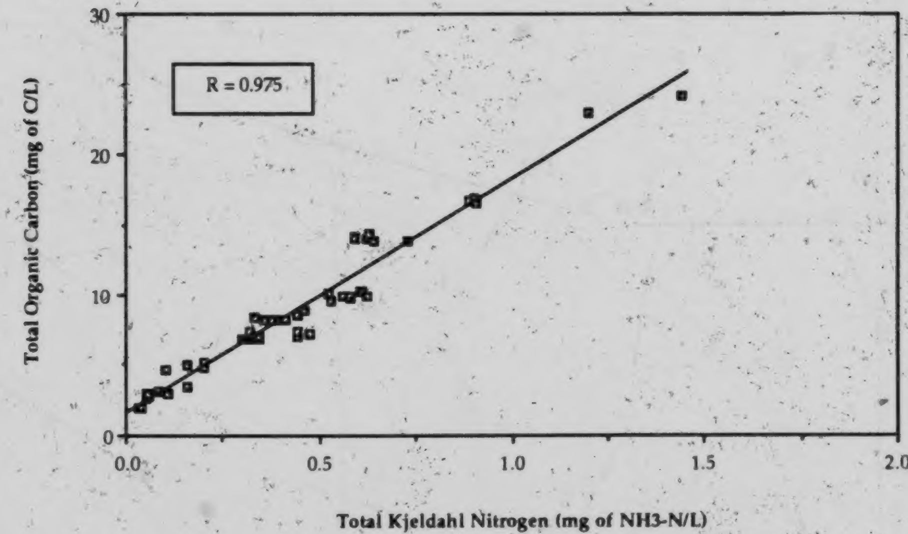


Figure 6.47 Correlation Between TOC and TKN at Facility I. Data for all 6 Days of Sampling.

6.1.5 Total Organic Carbon

The following general observations for total organic carbon (TOC) were observed for Pool I. As showed in Figure 6.48, TOC results are relatively homogeneous from one sampling point to another for a given pool at a given time. Daily profiles are showed in Figure 6.49, they were not very distinct although for a given day a tendency can be observed but the same pool showed different tendencies on different days. One general characteristic that stands out was the observation of higher TOC concentration in heated pools and also the fact that those latter pools show greater seasonal changes in TOC levels. Pool I-B was again the cleanest pool with respect to TOC levels. Profiles between the two seasons tested were not distinct and do not provide a generalized trend one way or another.

Pool II by comparison showed a definite difference between the two seasons with the summer sampling presenting the highest concentration in comparison with the fall. The TOC levels were consistent in both seasons Pool II-α and Pool II-β have similar levels and the two hot tubs, Pool II-χ and Pool II-δ, have the highest TOC concentrations. As can be seen in Figure 6.50, there was no daily profile with respect to different sampling time.

Pool III presented the TOC levels with the most consistency even between sampling seasons, as showed in Figure 6.51. Although, the concentrations were slightly less in the summer, the difference is only about 0.7 ppm between the two seasons. Looking at the results over a daily time profile performed in the fall the difference is about 0.2 ppm. The water sample from the filtration unit feed line was 5.75 ppm. This was within the previously mentioned deviation of 0.2 ppm when compared to the level found in the pool.

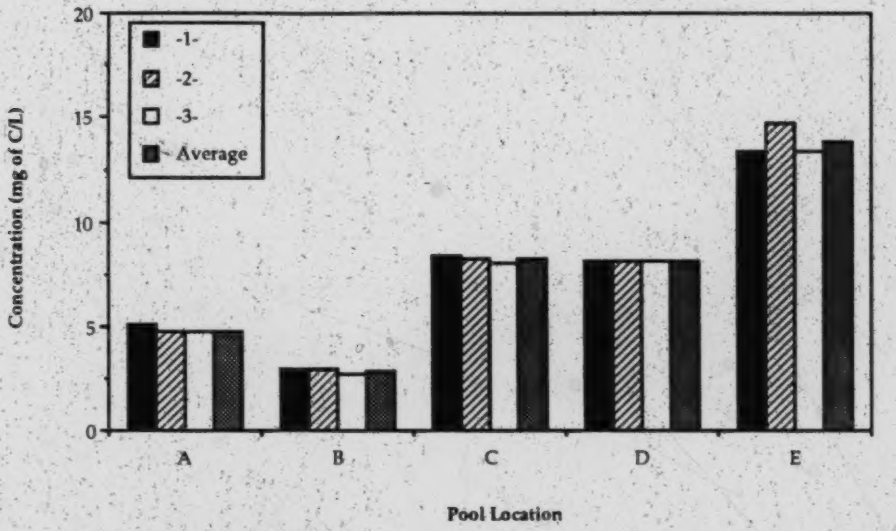


Figure 6.48 TOC Profile for Facility I on August 1, 1990. Study of pool Profile with Respect to the Different Locations.

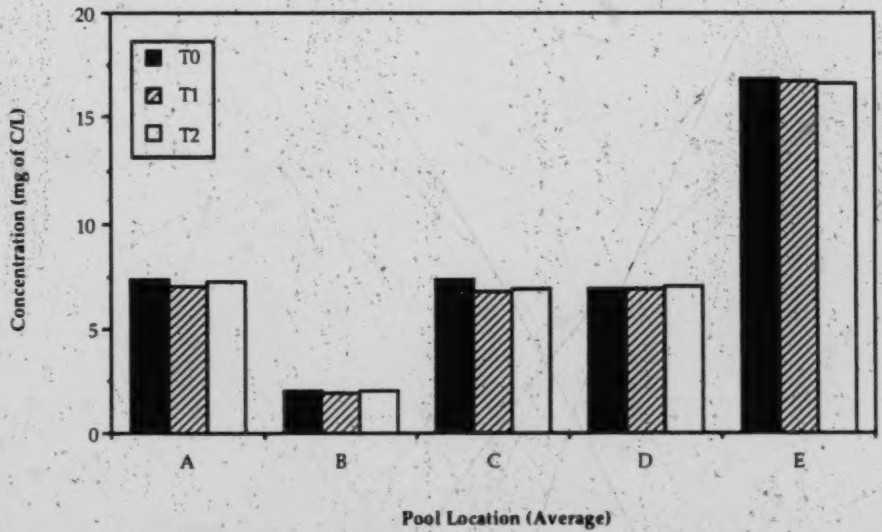


Figure 6.49 TOC Profile for Facility I on October 9, 1990. Study of Daily Profile Based on Average of Different Locations. T0, T1 and T2 Correspond to 0 h, 3 h and 6 h Sampling Intervals.

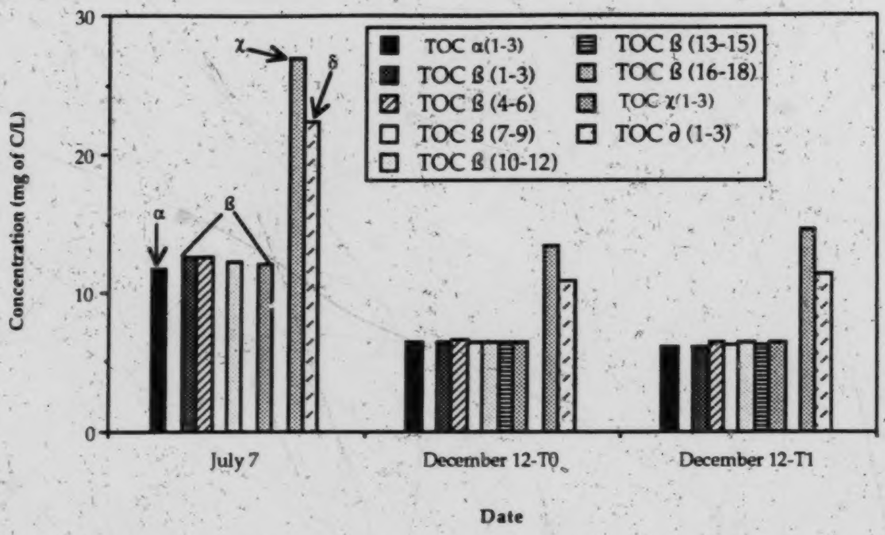


Figure 6.50 TOC Profile for Facility II. Study Showing Seasonal Profile, Pool Profile and Daily Profile.

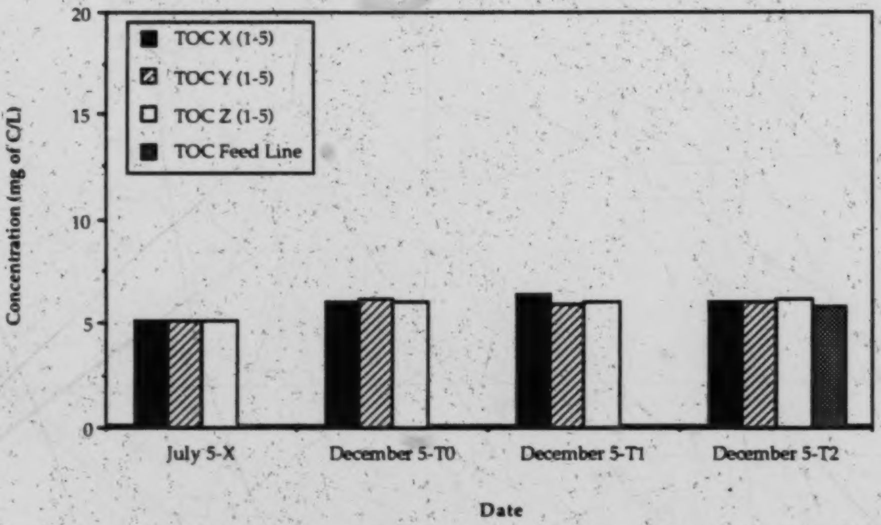


Figure 6.51 TOC Profile for Facility III. Study Showing Seasonal Profile, Pool Profile (Based on Different Sections: X, Y and Z See Figure 4.7) and Daily Profile. T0, T1 and T2 Correspond to 0 h, 3 h, and 6 h Sampling Intervals.

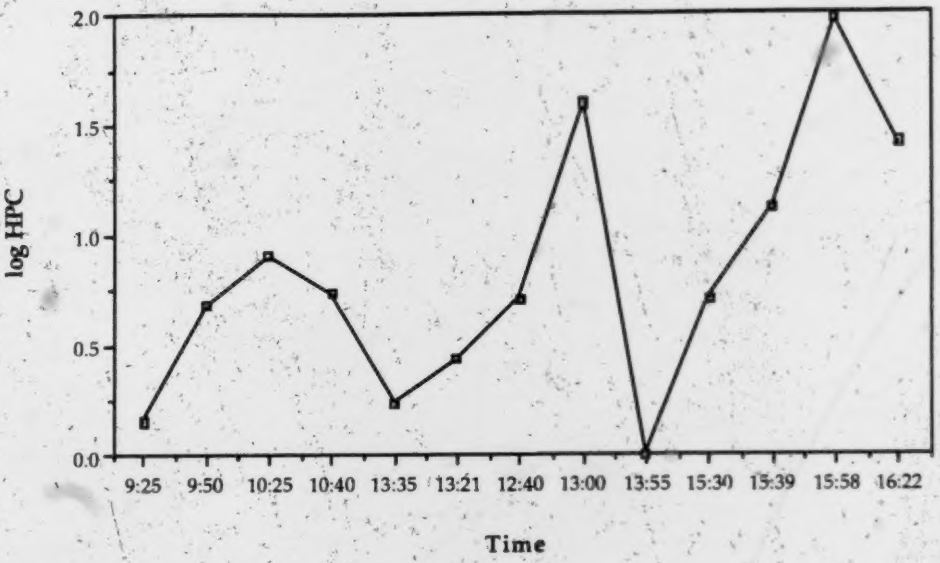
6.1.6 Cross-Correlation Between Measured Parameters

Time profiles about various parameters are presented in the following figures under this section. Additional correlations between the chemical, physical and microbial parameters measured are attempted. The figures relate to Facility I on November 29, 1990.

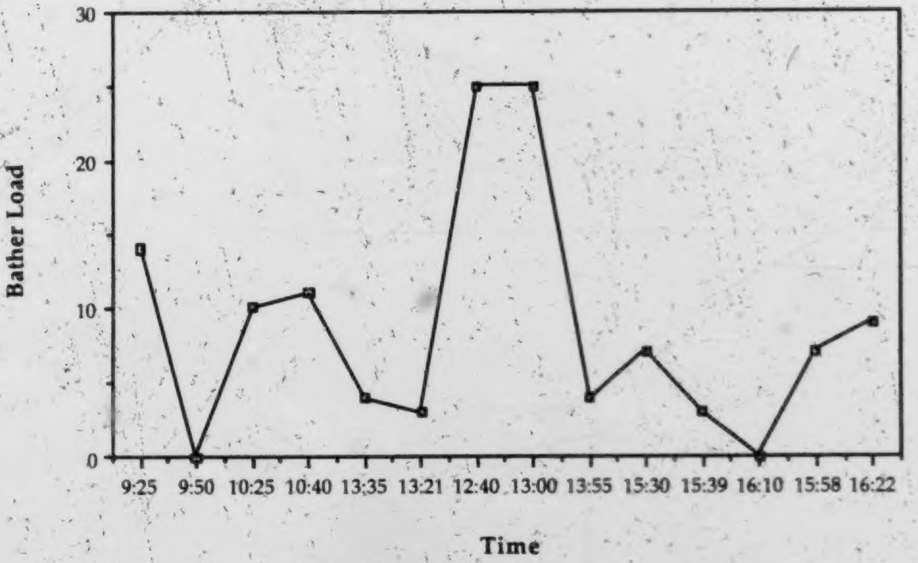
Figure 6.52 (a) shows the log plot of the heterotrophic plate counts (HPC) as a function of time for all the pools at Facility I. Figure 6.52 (b) shows the fluctuation of bather load as a function of time for all the pools at Facility I. The highest peak correspond to lunch hour, with some intermediate peaks in the morning and late afternoon. This Figure is a typical representation of the distribution of bathers at the facility. The comparison between the log plot of HPC and bathers fluctuation as a function of time is very good.

The next two figures (see Figures 6.53 (a) and (b)) represent the variation of organic loading and conductivity as a function of time for each individual pool at the site. The legend accompanying the plot indicates which data correspond to each individual pool. As can be seen from the figures, no change was observed throughout the day for either TOC or conductivity measurements with respect to a given pool with the exception of the conductivity for Pool I-B. The absence of daily profile for TOC was showed earlier with bar graphs (see Figures 6.49 to 6.51). In addition, the absence of pool profile is also demonstrated. The three points for each individual pool at a given sampling time are overlapping or are very tight.

The following series of figures, show the variation of microbial activity (log HPC), organic loading (TOC) and conductivity of the water with respect to bather load for each individual pool as a function of time. Figures 6.54 (b) and (c) follow a similar pattern demonstrating a correlation between the organic load and the conductivity. Figure 6.54 (a), representing the

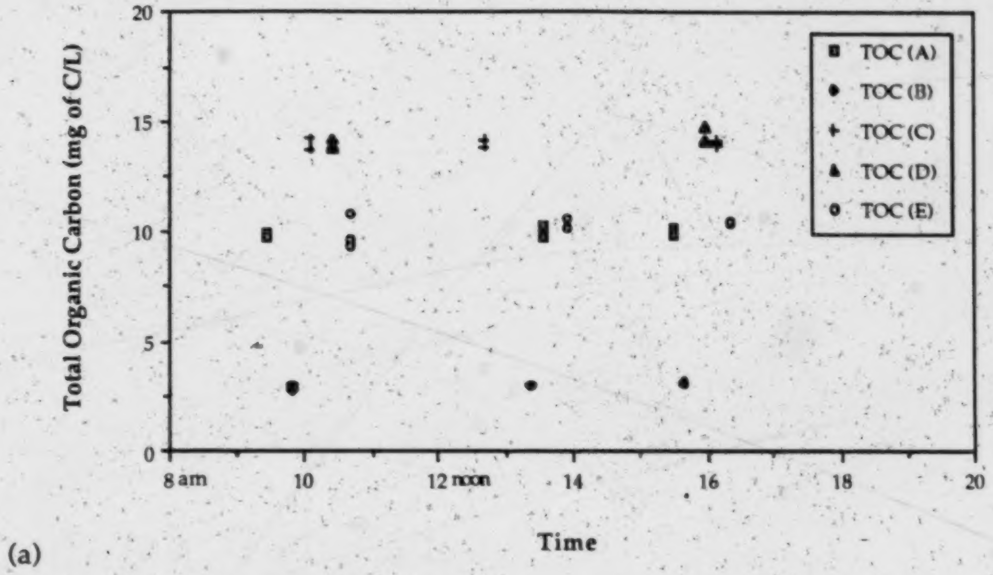


(a)



(b)

Figure 6.52 (a) Log Plot of HPC as a function of Time and
(b) Bather Load Fluctuation During the Sampling Day of November 29, 1990 at Facility I.



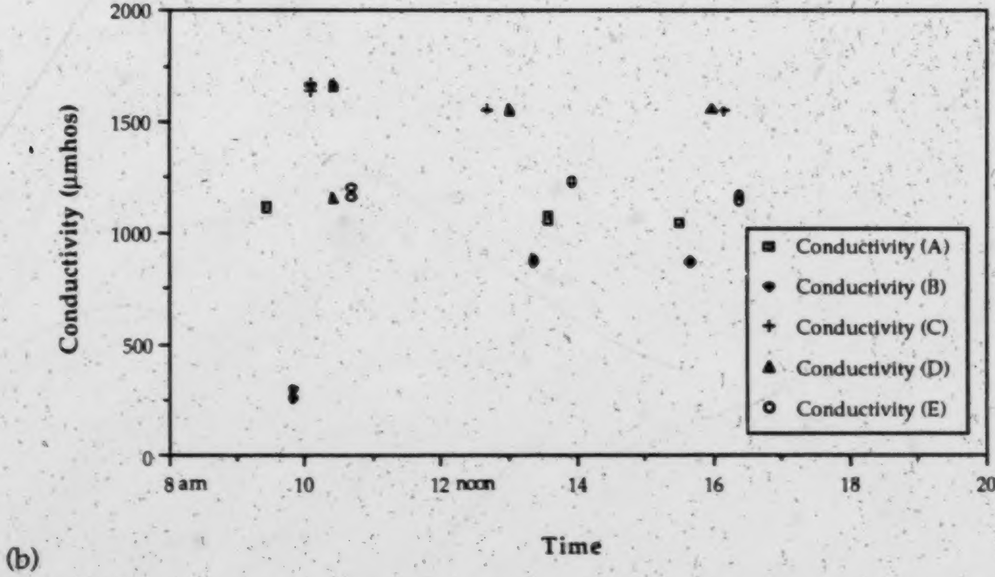
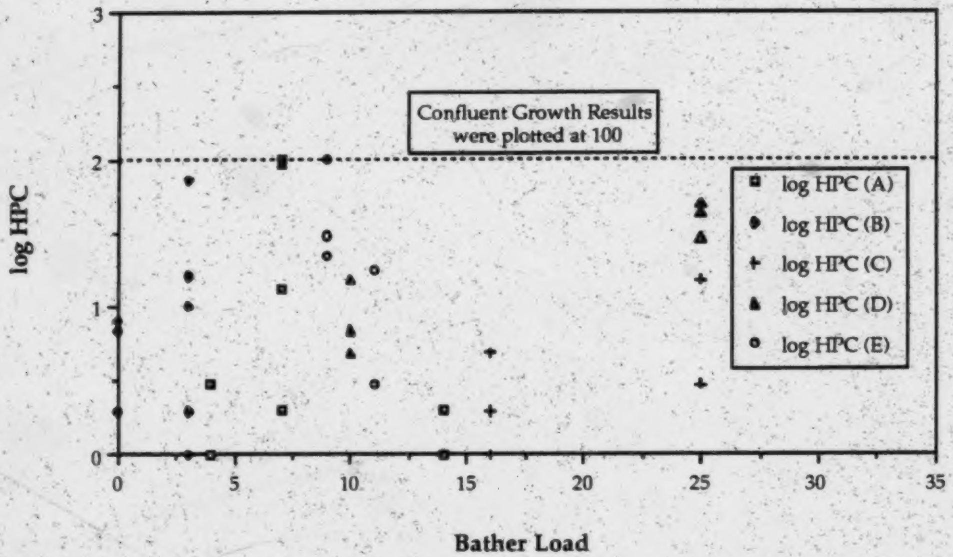
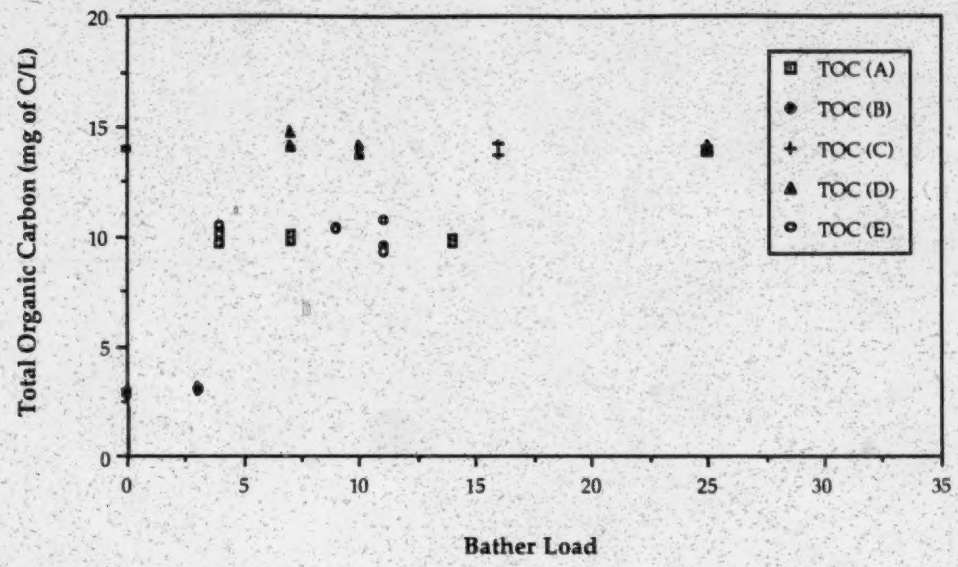


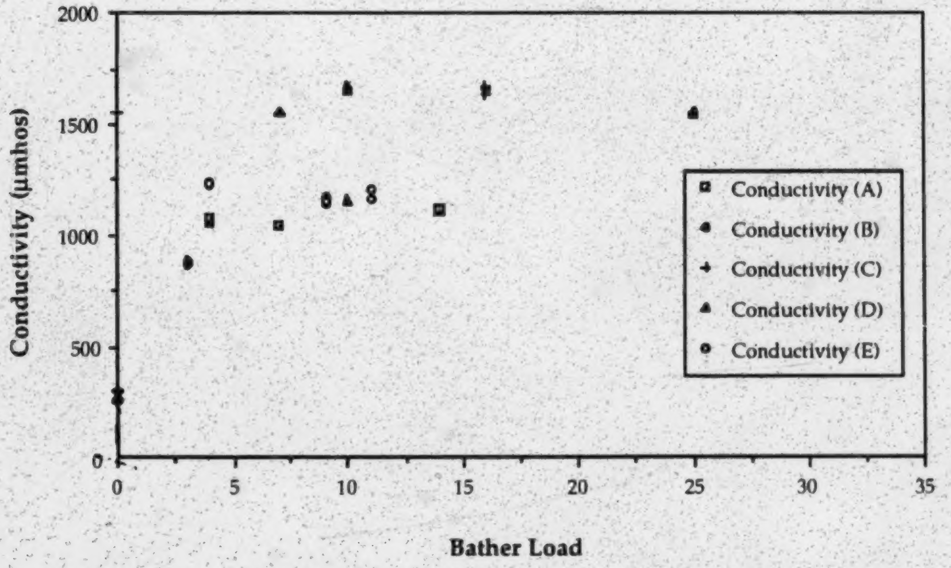
Figure 6.53 (a) TOC Fluctuation as a Function of Time and
(b) Conductivity Fluctuation as a Function of Time.


3
2
1
0
log HPC
Confluent Growth Results were plotted at 100
log HPC (A)
log HPC (B)
log HPC (C)
log HPC (D)
log HPC (E)
0
5
10
15
20
25
30
35
Bather Load

(a)



(b)



(c)

Figure 6.54 (a) Log of HPC Fluctuation as a Function of Bather Load,
(b) TOC Fluctuation as a Function of Bather Load and
(c) Conductivity Fluctuation as a Function of Bather Load During the Day of November 29, 1990.

microbial activity, shows a mixed pattern with no definite tendency. The results obtained for each individual location are further apart, demonstrating local pockets of microbial activity in each pool. The local pockets of microbial activity were also reported by Mallmann (1962).

The next series of Figures correlates the microbial activity with the chlorine species encountered in the water (see Figure 6.55 (a), (b) and (c)). Again no definite trends were observed.

Figures 6.56 (a), (b) and (c) show variation of chlorine species for each individual pool as function of time. The general trend shows a slight tendency for the disinfecting species to decrease during the day. This would explain the increased frequency of "Confluent Growth" observed at the end of the day for the different indoor swimming pools participating in this study (qualitative observation).

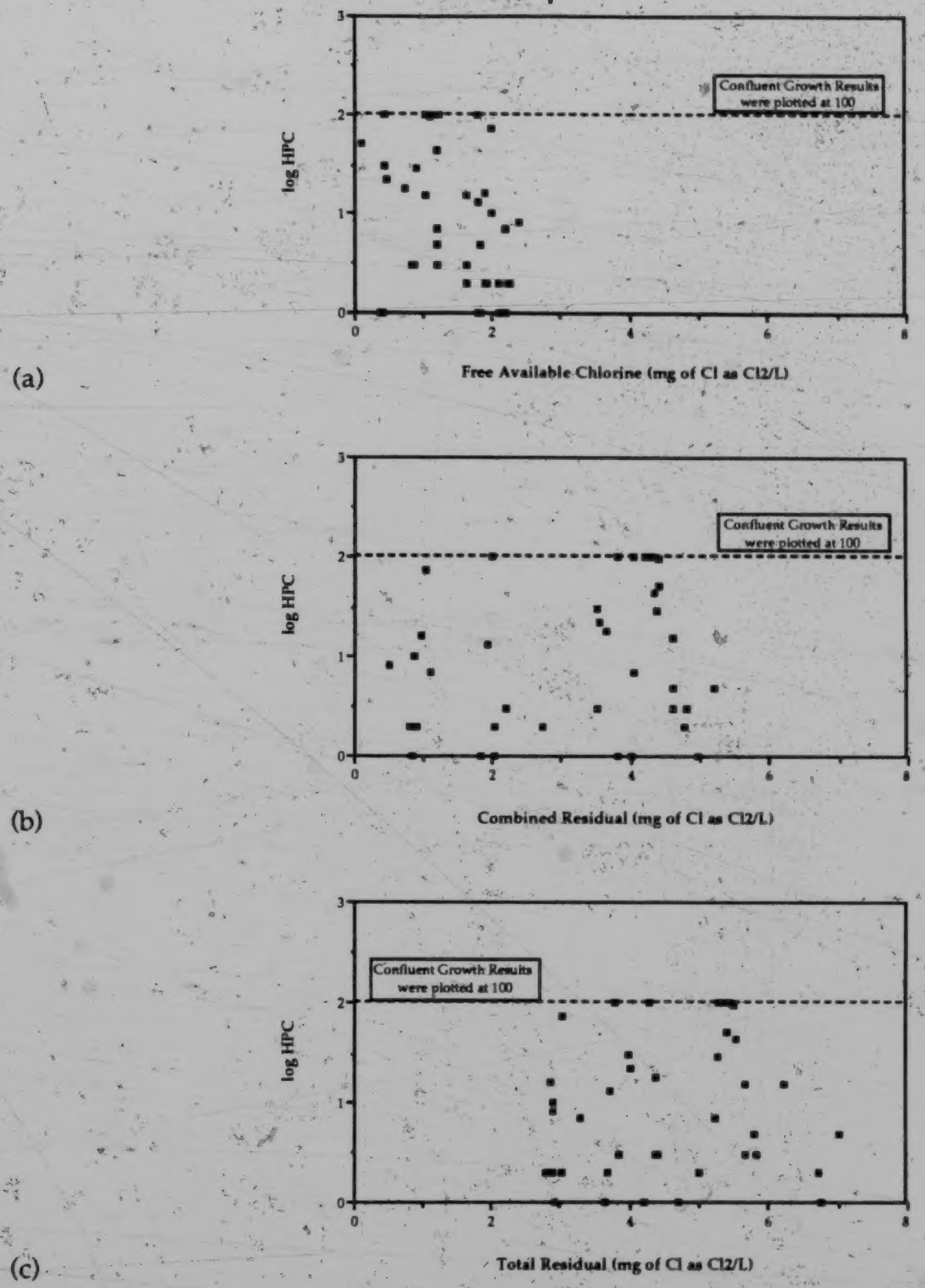
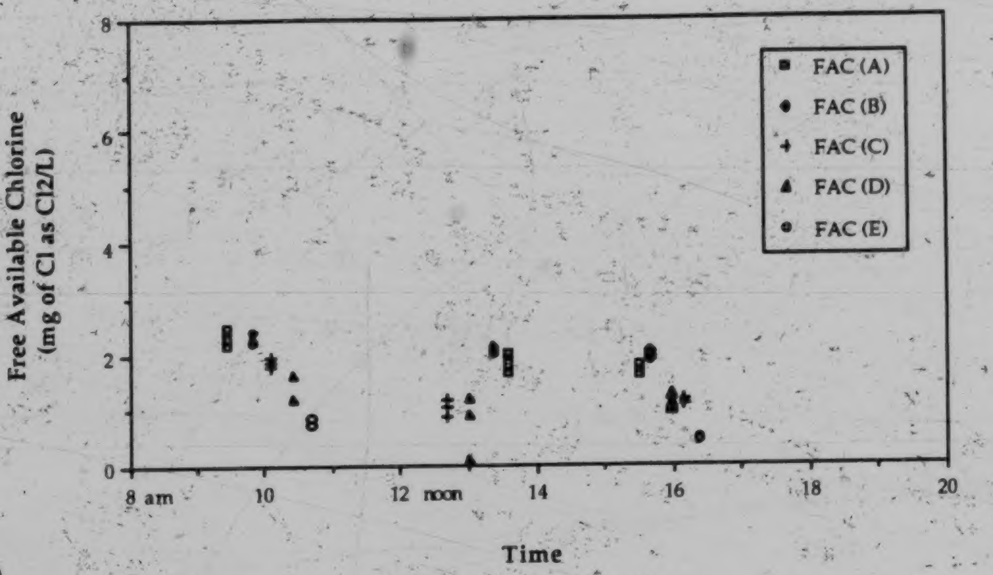
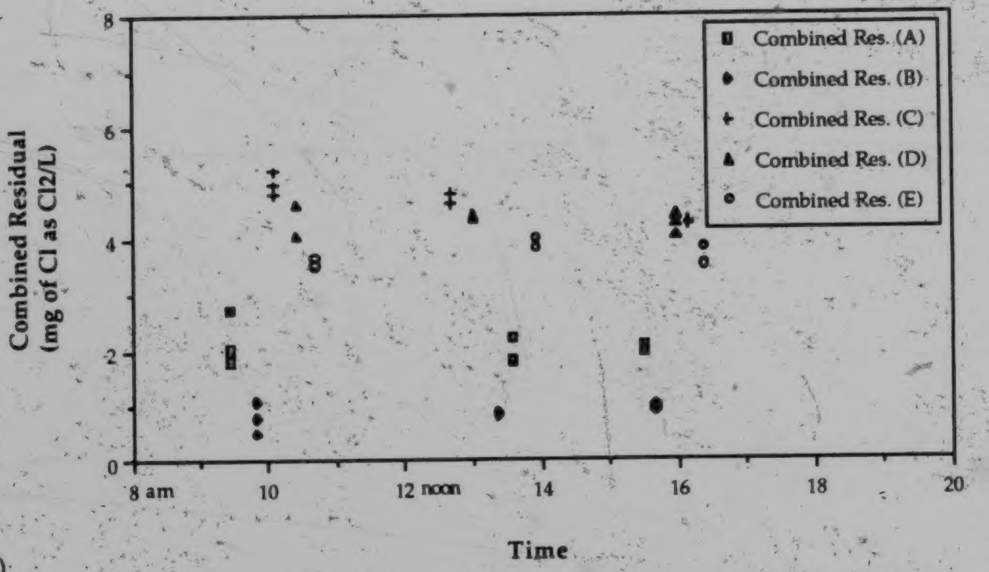


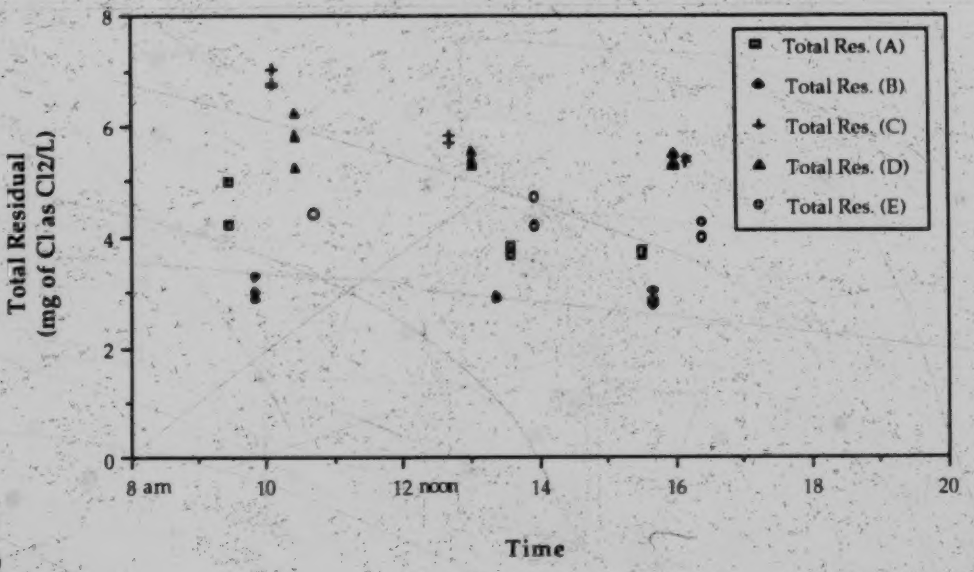
Figure 6.55 (a) Log of HPC Fluctuation as a Function of FAC,
(b) Log of HPC Fluctuation as a Function of Combined Residual,
(c) Log of HPC Fluctuation as a Function of Total Residual During the Day of November 29, 1990.


Free Available Chlorine
(mg of Cl as Cl2/L)
0
2
4
6
8
8 am
10
12 noon
14
16
18
20
Time
■ FAC (A)
● FAC (B)
+ FAC (C)
▲ FAC (D)
○ FAC (E)

(a)


Combined Residual
(mg of Cl as Cl2/L)
0
2
4
6
8
8 am
10
12 noon
14
16
18
20
Time
■ Combined Res. (A)
● Combined Res. (B)
+ Combined Res. (C)
▲ Combined Res. (D)
○ Combined Res. (E)

(b)



(c)

Figure 6.56 (a) FAC Fluctuation as a Function of Time,
(b) Combined Residual as a Function of Time and
(c) Total Residual as a Function of Time During the Day of November 29, 1990.

6.1.7 Large Volume Aqueous Sample Extraction

The large volume aqueous sample extractions were performed only in the second phase of the sampling program to provide more complete background information on the organic chemical loading present in the water phase. This analysis provides only qualitative results based on tentative identification by GC/MSD of a wide range of contaminants present in the water phase. The results have been separated according to the pH of the water at extraction. The tables provide information about the retention times, the name of the tentatively identified compounds, molecular weight and quality of the match. Details are provided in Appendix D5.

The acidified extractions resulted in a larger amount of compound for all three swimming pool water tested. Swimming pool water from Pool I-E, Pool II-χ and Pool III section Y were analyzed. A large number of compounds were found but only a small proportion of peaks were tentatively identified (see Table 6.1 for the acid extract). Most tentative identifications were poor MSD fits. However two families of compounds stood out. Compounds containing nitrile group and compounds containing carboxylic acid group. The nitrile containing compounds would be expected according to the chlorine amino acid reactions that yield aldehydes or nitrile depending on pH and chlorine/amino acids ratio. These findings about a common mechanism of formation of aldehydes and nitriles have been reported in previous research by Hrudey et al. (1989) and were discussed in section 2.1.1.3. Figure 6.57 shows the total ion chromatogram (TIC) for the acid aqueous extract for Pool I-E.

Table 6.1 Large Volume Aqueous Acid Extraction for Pool I-E.

Retention Time	Compound	Molecular Weight	Probability by MSD
4.426	unknown		
5.191	unknown		
10.174	3-chlorobutanenitrile	103	53
12.16	unknown		
12.643	benzaldehyde	106	94
13.567	butanedinitrile or iso	80	86
16.309	2,2,dichloro acetamide	126	47
16.421	pentanedinitrile or iso	94	53
17.71	unknown		
18.304	unknown		
18.817	benzeneacetonitrile	117	96
20.37	unknown		
22.359	ammonium salt of benzoic acid	139	72
24.274	phenyl propanedioic acid	180	86
25.006	nonanoic acid	158	70
27.081	decanoic acid	172	70
27.408	decanoic acid	172	86
28.555	bis (1-methylethyl)hexanedioic acid	230	83
29.545	undecanoic acid	186	89
29.931	unknown		
30.149	unknown		
30.872	unknown		
37.279	unknown		
31.784	diethyl phthalate	222	
32.38	dodecanoic acid	200	94
33.352	unknown		
33.471	unknown		
33.659	unknown		
33.857	unknown		
34.313	tridecanoic acid	214	94
35.653	unknown		
36.695	tetradecanoic acid	278	98
36.943	unknown		
37.638	unknown		
37.976	unknown		
38.561	pentadecanoic acid	242	96
39.216	2,5 dihydro-2,5-methoxy furan	130	
40.655	hexadecanoic acid	256	93

Table 6.1 (Continued) Large Volume Aqueous Acid Extraction for Pool I-E.

Retention Time	Compound (Continued)	Molecular Weight	Probability by MSD
41.548	long chain alkane		
41.776	unknown		
43.472	long chain alkane		
43.78	unknown		
44.435	octadecanoic acid		low
45.348	long chain alkane		
45.487	... benzene dicarboxylic acid	334	87
45.596	phthalate		
45.686	phthalate		
45.795	phthalate		
45.924	phthalate		
46.033	phthalate		
46.152	phthalate		
46.231	phthalate		
46.479	phthalate		
46.608	phthalate		
47.155	long chain alkane		
48.88	long chain alkane		
49.316	phthalate		
50.533	long chain alkane		
51.512	long chain alkane		
52.282	long chain alkane		
54.357	long chain alkane		

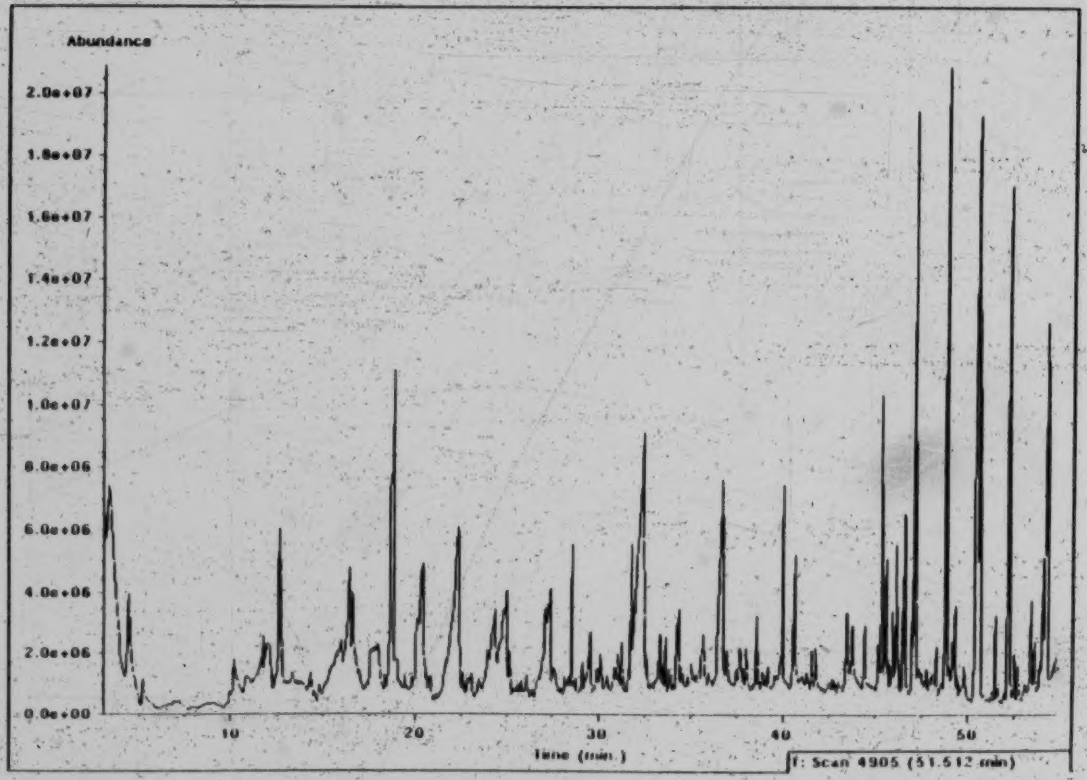


Figure 6.58 Total Ion Chromatogram for the Concentrated Aqueous Acid Extract for Pool I-E on November 29, 1990.

The method employed is very harsh for volatile compounds, with respect to the Kuderna-Danish concentration procedure. The smallest compound observed was butanedinitrile with a molecular weight of 80 g/mole. Alkanes and some rare halogenated compounds were also found, this time in the neutral extraction of the swimming pool water. Compounds found were quite similar among all three swimming pools tested.

6.2 Air Sampling

6.2.1 2,4-DNPH Pool Sampling

Analysis of the air phase on October 9, 1990 from Pool I by the air sampling adsorption tube provided no information on the concentration of aldehydes present in the air phase. Initial work had been attempted on GC/ECD without success. The chromatograms were not very well defined and the peaks that were present were in higher concentrations in the method blank. On October 16, 1990, a hydrazone standard of each formaldehyde and acetaldehyde, as well as, an air sample from October 9, 1990 were analyzed by GC with mass selective detection (MSD). The retention time and presence of the formaldehyde hydrazone were confirmed in the one air sample from Pool I. The sample had been taken over Pool I-E for a sampling time of 30 min at a flow rate of 2 L/min. Although the presence was confirmed, it was not possible to determine the concentration, since the sample had to be concentrated under a stream of nitrogen leaving a very small peak with a fairly strong background. Moreover, the levels in the method blank were, as in the GC/ECD analysis, still more important than in the sample itself making the confirmation of the hydrazone in the air sample less credible. Further experiments tried to deal with the highly contaminated background of the coated silica gel to obtain better definition of the air contaminants sampled, if any, with respect to the background levels.

Resin was used in an effort to clean-up the background contaminants from the coated silica gel. Different approaches were tried in order to provide a better quality of coating at the start. Carbonyl free solvent was prepared and more thoroughly dried coated silica gel was used, but nothing seemed to provide the required improvements.

The following sections will discuss all the different experimental attempts that were tried to finally explain why it was not possible to quantify aldehydes in the overlying atmosphere at Pool I and also why it was initially judged to be of limited value to pursue further testing at the other sites involved in the study.

6.2.2 Recovery Trials

Recovery trial tests were designed to evaluate the quality of the sampling involved when using the adsorption tube technique developed in this project. Basically, a known amount of aldehyde was spiked into the flow of nitrogen leading to the heated generated ampoule in series with the sampling tube and pumps. The coated silica gel was then extracted as described in section 5.2.1.7 and analyzed by GC/FID to confirm the amount of hydrazone recovered from the spike by making use of a calibration curve for the hydrazone.

The recovery trials were performed with acetaldehyde. This aldehyde was judged to be the most likely to be detected at swimming pool sites because its aqueous concentrations were close to formaldehyde but acetaldehyde has a much higher air-water partition coefficient.

The results from the open setting vary from 130% to 23% recovery with the lowest yield corresponding to the highest concentration spiked. The results show that increasing spiked concentrations were recovered in decreasing yield. Therefore the open setting was questionable in that vaporized aldehyde might be escaping the generating ampoule from the open top.

Table 6.2 Recovery Trial with Acetaldehyde Using Open System.

Concentration Spiked µg/L	Concentration Recovered µg/L	Recovery Efficiency %
0	0.0445	-
0.1138	0.1478	130
0.2277	0.2030	89
0.5692	0.2826	50
0.5692	0.2161	38
1.1383	0.2655	23

To avoid such losses a second closed setting was also tried. Lower yields were obtained in this experiment. These lower yields gave the opportunity to conclude about the importance of contact time. Forcing the aldehyde to go through the sampling tube faster by apply a greater nitrogen pressure, resulted in shorter contact time. This resulted in less time for the aldehyde to react with the reagent on the surface of the coated silica gel. At the lower concentration a much poorer yield than before was obtained, 38% compared with 130%. This would also provide evidence to assume that poorer yields result from shorter contact time as concentration was increased in the open setting. Since the reaction occur at the surface there might not have been enough free site to allow sufficient time to react with the 2,4-DNPH reagent when higher concentration were spiked.

Table 6.3 Recovery Trial with Acetaldehyde Using Closed System.

Concentration Spiked µg/L	Concentration Recovered µg/L	Recovery Efficiency %
0	0.0079	-
0.0918	0.0347	38
0.4990	0.1008	20

Additional tests involved the use of 2 g of coated silica gel, instead of 1 g, which would allow an increased contact time at the same flow rate since the packing was now 8 cm in height instead of 4 cm. However the suction action of the pump was found to be too weak to draw the air through within the 5% accuracy required by the program low flow (PLF) trip time, resulting in continuous stopping of the pump suction.

6.2.3 Controlled Water Basin Trials

The controlled water basin studies were performed to address the question of detectability of an aldehyde concentration in the air phase from a known water aldehyde concentration under conditions representative of a non-ideal system. Based on the extrapolation of the known concentration of aldehyde in the aqueous media and through calculation with the equations and partition coefficients described in Betterton and Hoffmann (1988) an expected air-phase concentration was calculated under ideal conditions.

The actual concentrations recovered in the air phase were, as expected, much lower than the expected air-phase concentration under ideal conditions. Less then 4% of the calculated aldehyde concentrations were collected over a water basin with a known concentration in water. Furthermore, the controlled experiment used aldehyde concentration that were ten times higher than the worst aldehyde concentration encountered at the swimming pool in the water phase. This factor was introduce to improve chances of detectability. The very low aldehyde concentration recovered under the much higher concentrations used, in combination with recovery under 100% makes it virtually impossible to talk about valid quantification of the air phase level, unless a very good reproducibility of recovery efficiency for a given concentration can be established as a correction factor.

Under section 6.2.2, replicate analyses of a spiked concentration of 0.5692 μg of acetaldehyde/L of air gave 50% and 38% recovery efficiency, giving an unacceptable margin of error at that concentration. With respect to the upper and lower limits determined by the recoveries mentioned a 34% error would be possible. On the other hand, the qualitative approach would permit the confirmation of the presence as well as an approximation (with a large error) of air phase levels as low as 35 μg/m^3 (16 ppb) for acetaldehyde and 67 μg/m^3 (54 ppb) for formaldehyde (under laboratory conditions). However, even the highest aqueous concentrations of formaldehyde and/or acetaldehyde at the pools would result (under optimum conditions) in much too low air phase concentration (as calculated by the partition coefficients in Appendix D7.3) to be detectable by the air sampling tube method.

Because Pool I presented the worst level of aldehydes in the aqueous phase and the quantification was made difficult with respect to background artifacts, reproducibility in collection efficiency and much lower levels than predictable under ideal conditions, it was determined that quantification experiments at the sites presenting lower level in the water would be next to impossible.

6.2.4 Air Bag Sampling

Air bag sampling was tried to ensure that a broader background of potential air contaminants was surveyed. Experiments to ensure that formaldehyde and acetaldehyde could be differentiated were attempted with the high moisture background present in the samples.

The grab sample from November 1, 1990 from the overlying atmosphere at Pool I-E revealed no air contaminant other than carbon dioxide (CO_2) and methane (CH_4). The CO_2 was found at a concentration of 490 ppm and the methane was found at a lower concentration than the room air used to provide background correction for the moisture content, it was evaluated at 2 ppm. Furthermore there was no carbon monoxide (CO) or any other contaminants found. The level of detection permissible by the FTIR used was in the parts per million (ppm), while the earlier adsorption tube although more specifically applied for aldehydes permitted qualitative confirmation in the parts per billion (ppb) range.

Acetaldehyde and formaldehyde could have been distinguished by FTIR if concentrations at the ppm level were encountered. Figures 6.58 to 6.60 show the air sample taken at the swimming pool, and the possible differentiation between formaldehyde and acetaldehyde with the high moisture background.

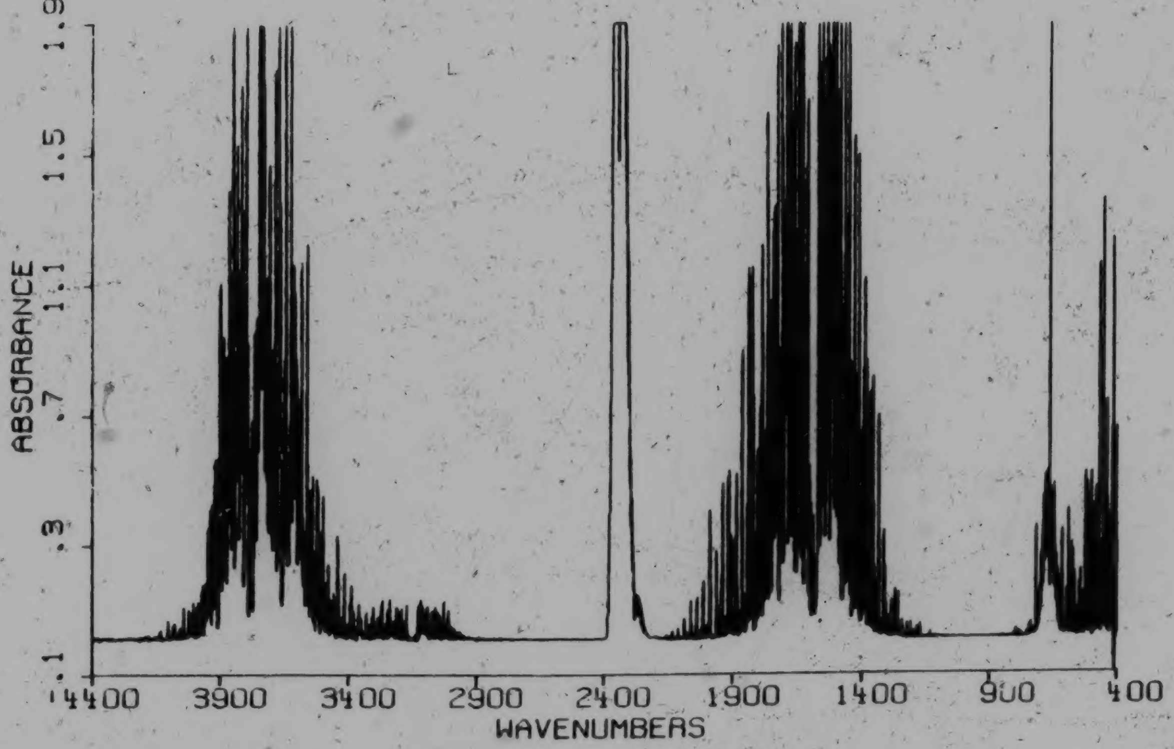


Figure 6.59 Air Bag Sample-FTIR Results for Overlying Atmosphere at Pool I on November 1, 1990 (Sample E1).

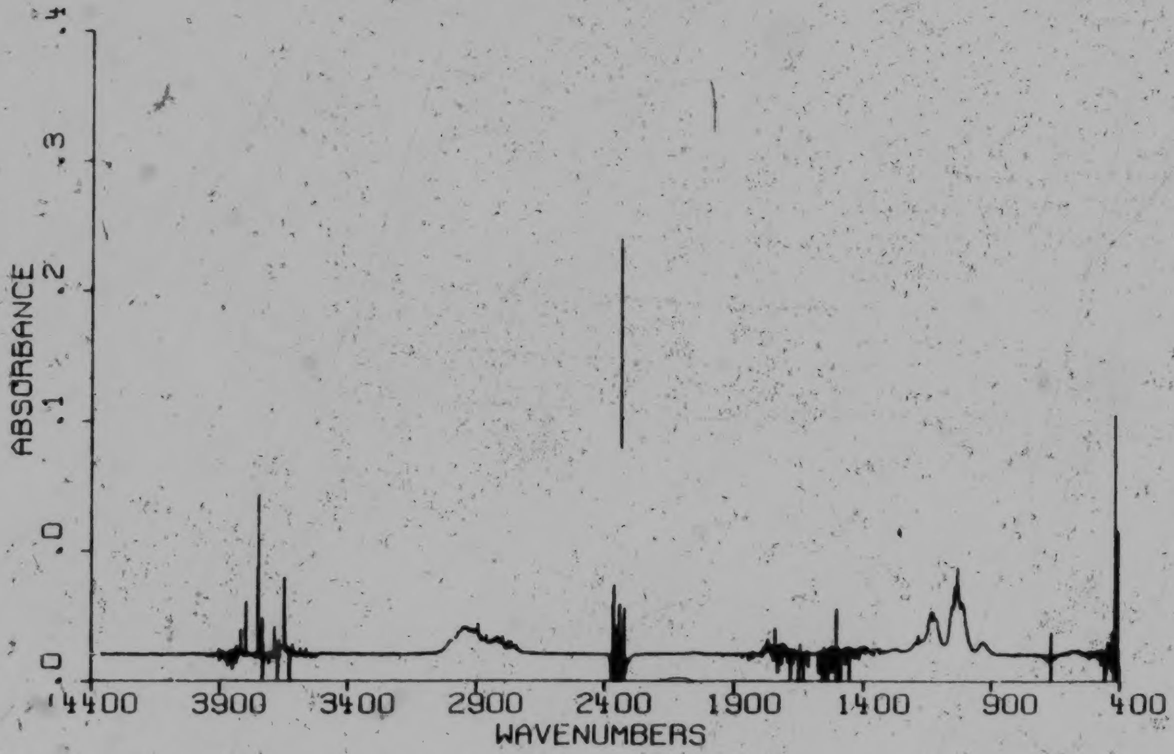


Figure 6.60 Air Bag Sample-FTIR Results for Formaldehyde Spiked Air Sample with Background Subtraction (Sample E2)

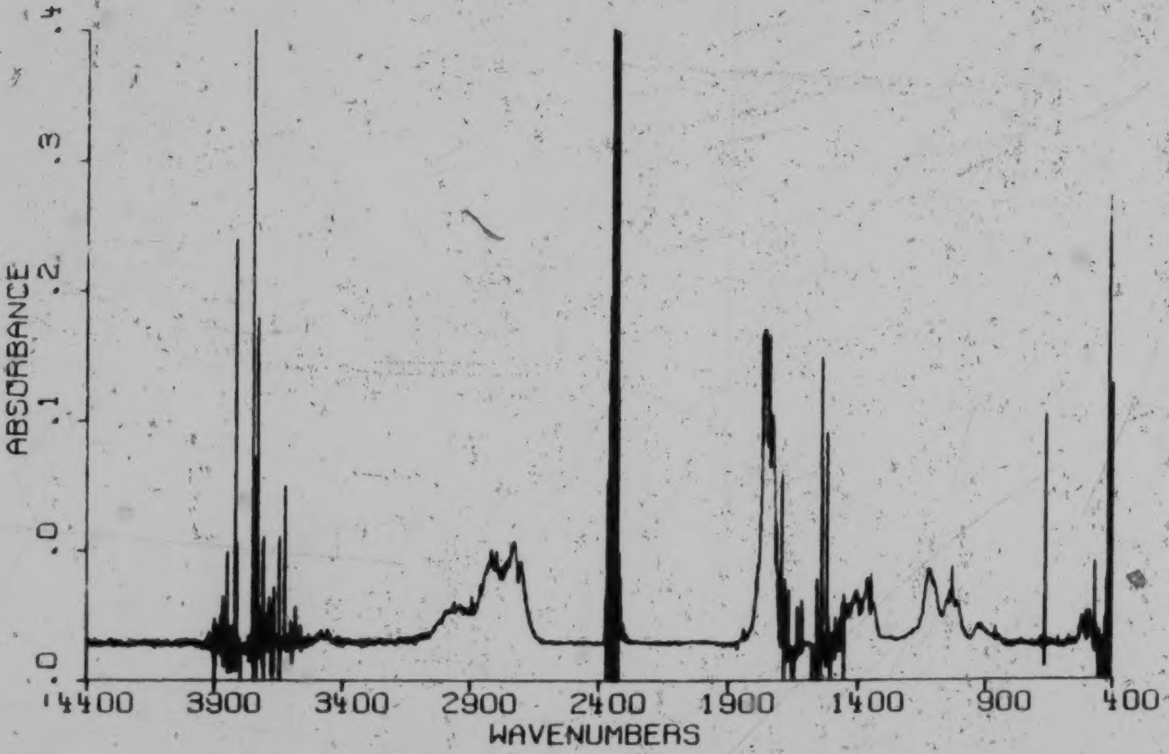


Figure 6.61 Air Bag Sample-FTIR Results for Acetaldehyde Spiked Air Sample with Background Subtraction (Sample E3).

6.3 Microbial Analysis

6.3.1 Aqueous Phase Microbial Results

The bacteriological water quality guidelines for swimming pools stipulate the following regulatory frequency:

> "...not more than 2 consecutive water samples and not more than 15% of the series of samples taken over a 6 month period..." (Section 15.4)

shall present adverse water quality conditions that contain or show: the presence of more than 200 bacteria per millilitre as determined by the standard 35°C plate count method; the presence of *Pseudomonas aeruginosa* in the case of swimming pools maintained at temperatures greater than 30°C; and the presence of coliforms in a 100 mL sample analyzed by the membrane filtration method.

All pools showed positive results for the presence of total coliforms (TC), as well as, fecal coliforms (FC). In general the TC and FC counts showed a tendency to increase during the day, which probably reflects the bather load and bather composition during the sampling period with respect to personal hygiene, age and sex. The types of coliforms found to be present included: *Escherichia coli, Enterobacter aerogenes, Klebsiella pneumoniae, Klebsiella oxytoca, Citrobacter freundii* and *Salmonella enteridis* (on one occasion only). With the exception of *Salmonella enteridis,* these organisms have been reported as part of the normal human genito-urinary and intestinal flora (Drasar and Roberts 1990, Ison 1990, Hill 1990). Under favourable conditions, these organisms may also be direct or opportunistic human pathogens (Lennette et al. 1985).

In order to determine, if TC and FC were part of the normal microbial profile of swimming pools on a regular basis rather than only on occasion, it would be necessary to survey the monitored swimming pools on a more frequent basis than was possible in this preliminary study. Also, the potential health risk contributed by these microorganisms could only be determined from a much more extensive epidemiological study than possible in this preliminary study. This latter survey would have to be in very close combination with a chemical/microbial survey for identification of chemical contaminants and microbial population as causative agents related to the symptoms experienced by the swimming pool users.

Total heterotrophic plate counts of the pool water samples usually met the regulations, except where "confluent" growth was recorded. The occurrence of confluent growth was encountered most frequently at Pool III. Again, more frequent sampling would be required to establish if the confluent growth prevailed on a routine basis or reflected some particular operational problem, which the samplers were not aware of during the time of the scheduled sampling. Occasional confluent growth was also noted at the other two sites surveyed, but they appeared more prevalent towards the end of the day, rather than at the outset, as was noted for Pool III.

Limited information was obtained from the other microbial indicators surveyed in the water phase, including fecal *Streptococcus*, and *Pseudomonas aeruginosa* in relation to the users symptoms. *Legionella* had been tested for the first phase of the program, but was not identified as being present in any samples.

As described in section 6.1.6, microbial activity as indicated by HPC in the Figures correlates very well with TOC, indicatives of source of substrate for the microorganisms growth. This correlation in turn also correspond with the conductivity measurements of the water and the bather load as the origin for the substrate and added particles.

6.3.2 Air Phase Aerosol Monitoring

Aerosol monitoring revealed a more diverse fungal population than the water phase and included the following organisms: *Aspergillus, Penicillium, Candida, Mucor, Rhizopus, Acremonium* species and actinomycetes. These organisms may act as potent antigens and are capable of causing a variety of allergic and pulmonary symptoms, as well as, bronchial obstruction in susceptible hosts in the population.

The preliminary aerosol monitoring performed was hampered by the fact that only a single aerosol monitor was available making adequate monitoring at each site difficult. Nevertheless, the limited available results from the aerosol monitoring and the results from the aqueous phase make the possibility of future exhaustive monitoring of the microbial quality of the air phase very interesting as potential vector of adverse health symptoms. One possible route of particular interest is the inhalation of endotoxin. Endotoxin is the lipopolysaccharide (LPS) of the outer membrane of Gram-negative bacteria (Schaechter et al. 1989). Gram-negative bacteria include species such as coliforms, *Pseudomonas* and many heterotrophic organisms which would contain LPS as part of their cell wall. Endotoxins are also known as pyrogens. The endotoxin species are capable of inducing diverse pharmacological and immunological changes at both low and high levels (Schaecter et al. 1989). At low concentration, endotoxins may generate symptoms from fever to increased antibody synthesis and inflammation. When present in larger concentrations, endotoxins can cause: shock, hypotension and disseminated intravascular coagulation (Schaecter et al. 1989). When the body is overwhelmed by sepsis of Gram-negative bacteria such as *E. coli, P.aeruginosa* or others, reactions mentioned earlier can be observed.

6.4 Health Significance of Results

Chlorination using chlorine gas is the most commonly used disinfectant in municipally owned public swimming pools and is the required disinfection method under the Provincial Regulation for Public Swimming Pools. The different dissociation and reaction products of chlorine gas in water containing ammonia or nitrogenous compounds are regulated under the Alberta Regulation 247/85. The presence of a residual free available chlorine in the swimming pool is commendable to ensure adequate disinfection of the water. However, a FAC residual does not ensure disinfection because of the regrowth and resistance of some microorganisms and therefore FAC can not be used as an indicator of adequate disinfection in replacement of actual bacterial and virus enumeration.

The level of combined residual are also regulated under the Alberta Regulation 247/85. The primary reasons are for optimum disinfection capacity and swimmers comfort. As it is well known the disinfection capacity of the so called "bound effective chlorine" (Lahl et al. 1981) is less then that of the free species (FAC). In addition, the combined residual composed of inorganic and organic chloramines is a source for concern with respect to bathers comfort. The "bound effective chlorine" is used as a measure of the potential for water to irritate the mucous membrane of swimmers (Lahl et al.

1981). The chloramine species are also suggested as a source for eye irritation (Crabill and Lyman 1963).

The trihalomethanes found in the swimming pools arise from the chlorination of water containing organic contaminants. Swimmers are exposed to TTHMs uptake when they are totally immersed in the water, at one time or another, and when they take water into their mouth and spit it out (Beech 1980, Kaas and Rudiengaard 1988).

The pathways of exposure are diverse and depend on the chemical and physical characteristics of the compounds. Dermal, oral, buccal sublingual (under the tongue), orbital, nasal, aural and inhalation are the pathways through which TTHMs can be up-taken by the swimmers. Estimates of the worst case trihalomethane body burden for swimming pool users are important (Beech 1980, Beech et al. 1980, Aggazzotti et al. 1990). A worst case body burden TTHMs uptake was estimated by Beech (1980) for a 5 to 9 year old boy weighing 21.9 kg and exposed for three hours of bathing in water supporting a concentration of 500 µg/L as $CHCl_3$. The up-take was found to be greater then if 2 L of water containing 100 µg/L of $CHCl_3$ were drank by the same boy.

Comparison of the trihalomethane levels found in the swimming pools participating in this study and the reported literature levels for the same parameters compare favourably presenting lower levels when excluding the peaks encountered at Facility I on October 9, 1990. These peaks represented unusual levels of chloroform and bromodichloromethane. The levels for THMs presented in Table 6.4 constitute an extract of the reported values in the available literature.

Table 6.4 Comparison of THMs Results with Values Reported in the Literature.

Parameter	Facility I	Facility II	Facility III	Beech et al. 1980	Lahl et al. 1981	Aggazzotti and Predieri 1986	Benoit and Jackson 1987	Aggazzotti et al. 1990
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
CHCl3	43-168	28-278	38-48	-	43-980	62-179	15-674	17-47
CHCl2Br	0-9	0-8	0-5	-	0.1-150	6.0-10	-	-
CHClBr2	0-113	0-117	0-27	-	0.1-140	0.8-2.0	-	-
CHBr3	0	0	0	-	ND-88	ND	-	-
TTHMs	43-290	28-403	38-80	125 (avg)	59-1224	68.8-181	-	-

ND: Not Detected
Note: The high values (Table D3.4.2) observed on October 9, 1990 are excluded.

Total Organic Carbon and Total Kjeldahl Nitrogen have been shown to correlate very well in this study (see Figure 6.47). They correspond to an increased burden on the FAC by reacting to form more noxious compounds such as the trihalomethanes, namely chloroform, and chloronitrogenous compounds of inorganic and organic nature. The resulting compounds also have reduced or no germicidal capacity and therefore serve no useful purpose.

There was no correlation between the TOC and the TTHMs results as was also reported by Benoit and Jackson (1987). Their explanation on the absence of correlation is illustrated quite convincingly in Figure 6.61. They attribute the absence of a correlation between TOC and TTHMs to long term use of the water in the pools. Combined with the long term use is the rapid exhaustion for fresh TOC to react with chlorine and produce TTHMs, in that each unit of TOC has a finite trihalomethane formation potential. This is in opposition to the correlation reported by Singer and Chang (1989) for drinking water treatment. The high volatility of the THMs will also contribute to keeping water phase concentrations lower.

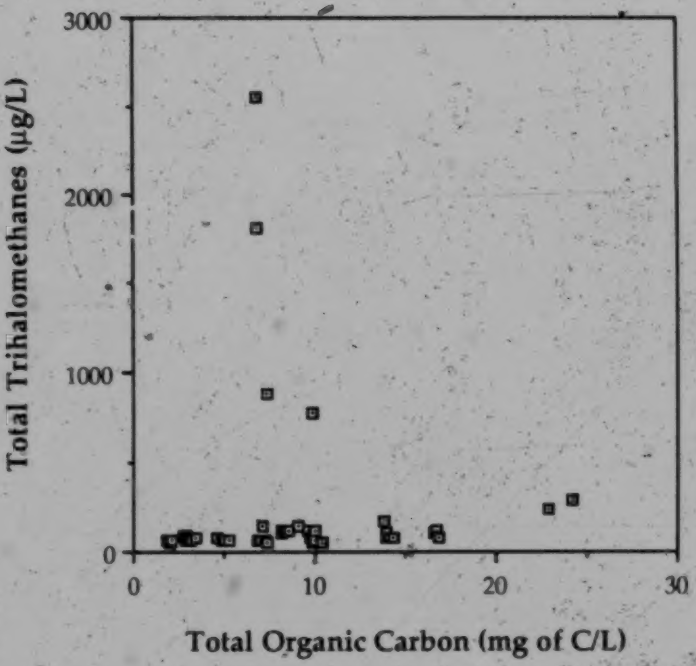


Figure 6.61 Correlation Between TTHMs and TOC at Facility I. Data for all 6 Days of Sampling. Showing the Limitation in Production of TTHMs in Respect with TOC Increase.

The aldehydes are not currently regulated for public swimming pools. In view of all the health effects that they are responsible for and the finding of high levels in the water phase, the health significance of aldehydes in swimming pools warrants further investigation. Figure 6.46 indicates a significant correlation between aldehydes and TOC (and TKN). These aldehydes appear to be formed in response to increasing levels of TOC (bather load). They do not appear to reach maximum levels independent of TOC as observed for TTHMs. Their relation in the water phase with the TOC may result from their much lower Henry's Law constants compared with the THMs.

Lists of microbial identification from the water phase analysis on an individual base for each facility are provided in Appendix E3 along with commonly reported clinical manifestations. Table 6.5 provides a comparison between the range of microbial results obtained from the three facilities participating in this study and previously reported results from the literature.

As earlier mentioned, FAC measurements as an indicator of adequate disinfection alone, is inadequate and should be done concomitantly with bacterial enumeration. As most of the disease contracted in swimming pools are skin related disease (Tosti and Volterra 1988), any additional microbial indicators should provide information about the hygienic condition of the water with respect to skin disease causing microorganisms, rather than the current emphasis on enteric disease causing microorganisms.

Table 6.5 Comparison of Range of Microbial Results Reported in this Study and in the Literature.

Species	**Facility I**	**Facility II**	**Facility III**	**Tosti and Volterra 1988**	**Schiemann 1985***	**Calderon and Mood 1982**
HPC (cfu/mL)	<1 to Confluent Growth	5 to Confluent Growth	<1 to Confluent Growth	16 to 15000	0 to >3000	3 to 2150
TC (cfu/100 mL)	<1 to Confluent Growth	<1 to 191	<1 to Confluent Growth	0 to 300	0 to 26	-
FC (cfu/100 mL)	<1 to Confluent Growth	<1	<1 to 12	0 to 42	-	0 to 1
Klebsiella (cfu/100 mL)	<1 to 28	<1	<1 to Confluent Growth	-	-	-
P. aeruginosa (cfu/100 mL)	<1 to Confluent Growth	<1 to Confluent Growth	<1 to 22	3 to 15000	0 to 4	0 to 2
F.Streptococcu (cfu/100 mL)	<1 to 50	<1 to 143	<1 to Confluent Growth	-	0 to 170	-

* Results provided are for a swimming pool disinfected by ozonation

In general the water quality observed at the the three Facilities was found to be indicative of some disinfection problems. Both the chemical aspect and the microbial aspect agree in that matter. Although, it was not possible to differentiate the inorganic chloramines from the organic chloramines, the high levels encountered were to the disadvantage of the swimming pool operators, whether they were trying to keep up with disinfection efficiency or swimmers comfort.

The aldehydes concentration were found to be in fairly high concentration at Facility I which has apparently been plagued by more complaints from the patrons. Aldehydes were notably lower at the two other facilities, though Facility II apparently to receives complaints as well. In addition, the combined residual levels were much higher at Facility I than at the other facilities.

Penny and Winter (1984) have suggested that swimming pool waters represent much more concentrated conditions than encountered in the drinking water industry but follow the same line of concern with respect to disinfection by-products. By extrapolation swimming pools would represent ideal media to study the mechanisms of production of irritant substances.

Table 6.6 shows the lower and upper limits for the different microbial species found in the aerosol samples at the three sites. These limits were extracted from the results tabulated in Appendix E2. As shown, Facility I presented the worst levels for bacterial counts with respect to both lower and upper limits. By comparison, the fungal counts were much lower than the bacterial counts and were among the lowest. Facility II presented the highest fungal counts. Solomon (1990) has reported the lack of occurrence of suspected health effects from exposure to microbial aerosols below 1000 cfu/m^3. The aerosol monitoring, in this present study, provided results that were well bellow the 1000 cfu/m^3 health effects limit reported by Solomon (1990). However, the same author does not exclude risks of microbially-induced health effects with lesser values.

Macher et al. (1991) have established useful baseline data representing "no complaints levels" for indoor air of apartment dwelling. A comparison of the microbial aerosol results obtained in the present study and the reported results by Macher et al. (1991) is also elaborated in Table 6.6. As shown, only the bacterial counts found at Facility I and Facility II would exceed the results reported by Macher et al. (1991). The fungal counts were always below the "no complaints levels" reported by the former authors.

Table 6.6 Lower and Upper Limits of Microbial Species Found in the Aerosol Samples at the Three Sites Under Study and Comparison with the Macher et al. (1991) Study.

Species	Facility I	Facility II	Facility III	Macher et al. (1991)
Bacteria cfu/m3	41 to 747	19 to 350	6 to 166	72 to 206
Fungi cfu/m3	6 to 28	3 to 116	0 to 19	148 to 351
Actinomycete cfu/m3	0	0 to 3	0 to 3	<1
Yeasts cfu/m3	9 to 13	0 to 78	0 to 6	NR

NR: Not Reported

7. CONCLUSIONS

Both potential sources of irritants, that is chemical substances and microorganisms, have provided some useful information as to the possible sources of irritation.

The very important aqueous levels of total aldehydes, basically present as formaldehyde and acetaldehyde, at Pool I differed greatly from the levels encountered at the two other sites under investigation. This could be an important consideration in interpreting the epidemiological evaluation of the three sites under investigation. The peak trihalomethane levels found at Pool I, attracts attention to the possibility of short term high level exposures. The possibility of formaldehyde exposure via aerosol could not be fully assessed.

The apparent inadequate disinfection observed at Pool III, as demonstrated by frequent HPC confluent growth, does not correspond with increased health complaints compared with the other facilities. By comparison, the chemical parameters at Pool III were almost always lower when compared with the other sites in the study. Because Pool III has been free of specific complaints this implies that microbial factors alone, cannot explain the frequency of complaints from pool users.

There are a wide variety of possible health effects from either the microbial aspect or the chemical aspect and there is not likely to be a single cause of health complaints. A complex interaction of the different parameters evaluated from one and/or a combination of both sources would most likely be at the origin of the problems.

The aerosol results presented lower counts than the health effects limit of 1000 cfu/m^3 proposed by Solomon (1990). They were also lower than the reported "no complaints levels" by Macher et al. (1991) with the exception of the bacterial counts at Facility I and Facility II. However, the potential for irritation is still present, if the complex potential combination with the different contaminants present at swimming pools, in either the water or the air phase, is taken into consideration.

In addition, previous sensitization and personal pre-disposition will complicate the evaluation of the potential causes of environmental health problem at indoor public swimming pools.

The following tables summarize the chemical compounds that were found in the aqueous phase. Some contaminants have been quantified (Q) while others have only been tentatively identified (I). Given the large variety of chemicals tentatively identified and the many more which are still unknown, there is a need for a more exhaustive investigation to confirm the identity of other water phase contaminants.

Table 7.1 Summary of the Quantification of the Chemical Contaminants Present in the Aqueous Phase at the Different Facilities.

Chemical Compound	Facility I						Facility II		Facility III	
	July 26	July 30	Aug. 1	Aug. 6	Oct. 9	Nov. 29	July 7	Dec. 12	July 5	Dec. 5
Formaldehyde	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Acetaldehyde	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Propionaldehyde	Q	Q	Q	Q	Q	Q	Q	ND	Q	ND
Isobutanal	Q	Q	Q	Q	Q	ND	Q	ND	Q	ND
Butanal	Q	Q	Q	Q	Q	ND	Q	ND	Q	ND
2-Methylbutanal	Q	Q	Q	ND	Q	ND	Q	ND	Q	ND
Isoveraldehyde	Q	ND	Q	Q	Q	ND	ND	ND	ND	ND
Pentanal	Q	Q	Q	Q	Q	ND	Q	ND	Q	ND
2-Methylvaleraldehyde	Q	Q	Q	Q	Q	ND	Q	ND	ND	ND
Hexanal	ND	Q	Q	ND	Q	ND	Q	ND	ND	ND
Heptanal	Q	Q	Q	Q	Q	ND	Q	ND	ND	ND
Octanal	Q	Q	Q	ND	Q	ND	ND	ND	ND	ND
Benzaldehyde	Q	Q	Q	Q	Q	ND	Q	ND	Q	ND
Phenylacetaldehyde	Q	Q	Q	Q	Q	ND	Q	ND	Q	ND
Nonanal	ND	ND	ND	ND	Q	ND	ND	ND	ND	ND

Table 7.1 (Continued) Summary of the Quantification of the Chemical Contaminants Present in the Aqueous Phase at the Different Facilities.

Chemical Compound	Facility I						Facility II		Facility III	
	July 26	July 30	Aug. 1	Aug. 6	Oct. 9	Nov. 29	July 7	Dec. 12	July 5	Dec. 5
FAC	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Monochloramine	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Dichloramine	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Trichloramine	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Chloroform	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Bromodichloromethane	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
Dibromochloromethane	Q	Q	Q	Q	Q	Q	Q	ND	Q	Q

Table 7.2 Summary of the Chemical Contaminants Tentatively Identified in the Aqueous Phase at the Different Facilities.

Chemical Compounds	Facility I	Facility II	Facility III
Butanedinitrile or iso	I	I	I
Pentanedinitrile	I	I	I
Benzeneacetonitrile	I	I	I
Dimethyl phthalate	ND	ND	I
Bis(1-methylethyl)hexenedioic acid	I	ND	ND
N,N-diethyl-3-methyl benzamide	I	ND	ND
Diethylphthalate	I	I	I
Benzenedicarboxylic acid	I	I	I
Cyclohexanone	ND	ND	I
2,2,2-Trichloroacetamide	ND	I	I
Benzoic acid	ND	ND	I
Phenylpropanedioic acid	I	ND	ND
Nonanoic acid	ND	ND	I
Undecanoic acid	I	I	ND
Dodecanoic acid	I	I	I
Tridecanoic acid	I	I	I
Tetradecanoic acid	I	I	I
Pentadecanoic acid	I	I	I
Hexadecanoic acid	I	I	I
Benzene dicarboxylic acid	I	ND	ND
Benzyl buthyl phthalate	ND	I	ND
Dioctyl ester of Hexanoic acid	ND	I	ND

8. RECOMMENDATIONS

Further study will be required to obtain a clear understanding of the complex sources of potential irritants and their interaction at swimming pools. As the sources are diverse, the combination of the individual parameters have yet to be evaluated in the literature.

The chemical air sampling, by either the adsorption tube method or the air bag sampling method, was unable to detect target contaminants in the enclosed environment at swimming pools. As shown in the controlled water basin trials, the concentration of aldehyde that could be expected in the air phase following calculation with the air-water partition coefficient would be much lower then the present detection limit of either method employed.

Additional work will have to include better air sampling methods with much lower detection levels and perhaps closer to real time analysis, eliminating the need for laborious manipulations.

Methods to measure potential traces of chloramines and trihalomethanes in the air phase should be also developed. This would provide interesting information as the chloramines are of particular concern in the swimming pool industry with respect to lower germicidal capacity and irritant of the mucous membrane of swimmers (Lahl et al. 1981).

Trihalomethanes and other volatile chlorinated by-products have been reported in Table 2.2 to present a wide range of symptoms following exposure. The high aqueous concentrations found on October 9, 1990 at Facility I "disappeared" within the next sampling interval. The levels found for the following sampling time had decreased to their normal background levels. This would imply transfer of the aqueous THMs to the overlying atmosphere at a very fast rate as confirmed by their high Henry's Law constants.

The high water phase concentrations of chlorine species implies that oxidant species are also present in the air phase. These oxidants should be monitored as they are potential mucous membrane and lung irritants. Use of an iodide bubbler could potentially reveal some information about total oxidants and would be a rapid method of analysis.

In follow up to the chlorine speciation analysis, a degradation study and comparison between DPD ferrous titrimetric analysis and amperometric analysis were performed. These were designed to provide information on the origin of response obtained in the nitrogen trichloride step in each respective analyses. As mentioned earlier , the organic chloramines interfere with the determination of the inorganic chloramine species at that stage. It is important to determine the true composition of the results obtained, since nitrogen trichloride has been proposed as an important irritant in the swimming pool industry. The organic chloramines have not been characterized for their potential as irritants in swimming pool waters and further research would be desirable.

As it turned out, both chlorine methods tested are incapable of discriminating organic from inorganic chloramines. Lukasewycz et al. (1989) have reported a method that makes use of high performance liquid chromatography (HPLC) to differentiate between the organic and inorganic chloramine species. Further GC/MSD work should also be performed to complete a better picture of the tentative species identified.

In another approach, AOX measurements should be performed in subsequent research to acquire a better knowledge of the distribution of the chlorinated species present in water. These analyses could be performed in two steps. In a first step, the AOX analysis could be performed on the sample coming directly from the pool. In a second step, the sample could be purged and the remaining AOX determined. This would somewhat qualify the volatility of the contaminants present in the water phase and their potential for exchange with the water phase in aerosol and water flumes.

Early aerosol monitoring revealed interesting levels of Gram-negative species present in the air phase. Gram-negative bacteria contain a lipopolysaccharide called endotoxin, as part of their cell wall. Endotoxin has been reported to produce a wide variety of allergy-like symptoms (Schaecter et al. 1989). Individuals involved in activities where the environment presents large numbers of Gram-negative bacteria are subject to developing higher white blood cell counts, hemolytic complement and higher antibody levels to endotoxins (Lundholm and Rylander 1980). The latter group will experience higher incidence of nasal, ear and skin infections, as well as, a higher incidence of burning eyes and skin irritation. A more exhaustive aerosol program could reveal the full potential of these Gram-negative species in view of the symptoms described.

As carbon containing compounds are the source of food for heterotrophic organisms, it would be desirable to reduce the amount of organic carbon in water. This would further improve the quality of disinfection by reducing the source of compounds for halogenation reactions during the disinfection process. It would also reduce the levels of potentially noxious by-products being formed during the process.

Improved organic carbon removal could be achieved through granular activated carbon (GAC) filtration, ozonation (in conjunction with other processes), biological treatment and fresh water dilution.

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APPENDICES

APPENDIX A

Health Survey of Public Pool Users
Interviewer-Administered Questionnaire

HEALTH SURVEY OF PUBLIC POOL USERS
UNIVERSITY OF ALBERTA
1990
INTERVIEWER-ADMINISTERED QUESTIONNAIRE

Hi, my name is ____________ and I'm from the University of Alberta. I just need to be sure that you can speak English. Can you? Yes _____ / No _____. If not, cease interview!

OFFICE USE ONLY

Computer ID # ☐☐☐

Do you make regular use of this facility for: (Interviewer: If more than one use, please state the one which involves the most time in the facility):

(a) Competitive swimming/diving/synchronized swimming/other team training? Yes ___ / No ___ ☐

Please specify the events in which you compete: ☐

____

____

(b) Fitness swimming/aquasize classes/PARTICIPACTION?

Yes _____ / No _____ ☐

(c) Work? (e.g. lifeguard, maintenance, admin., etc.)

Yes _____ / No _____ No. of hours/week: _____ ☐☐

Occupation ______________________________

If 'Yes', read Consent form to subject.
If 'No' to (a), (b), and (c), then cease interview.

DEMOGRAPHIC INFORMATION

1. Pool Name (specify): ______________________ ☐

2. Interviewee Sequence # ☐☐☐ ☐☐☐

3. Interviewee initials: ___ ___ (first, last) ☐☐

4. Today's date: ______ ______ ______ ☐☐☐☐☐☐
Day Month Year

Time: _______ a.m./p.m. ☐☐☐☐

5. Sex: Male _____ / Female _____ ☐

6. How old are you? (in completed years): _____ ☐☐

7. What is your current postal code? _ _ _ _ _ _ ☐☐☐☐☐☐

For how long? _____ years &/or _____ months ☐☐☐

8. Do you remember your previous postal code?

_ _ _ _ _ _ ☐☐☐☐☐☐

For how long? _____ years &/or _____ months ☐☐☐

9. Number of people who live in your present house/ apartment? _____ ☐☐

PERSONAL CHARACTERISTICS

10. What was your main occupation over the past year? (specify occupation/industry/any chemicals that you work with/details): ☐☐

____

____

(eg. student, office, factory, unemployed, volunteer in ____________________, etc.)

For how long in total: _____ years &/or _____ months ☐☐☐

Father's occupation: ____________________ ☐☐

Mother's occupation: ____________________ ☐☐

11. How tall are you? _____ cm/ _____ ft and _____ in. ☐☐☐

12. How much do you weigh? ____ kg / ____ lbs (round up) ☐☐☐

13. Tobacco smoking history/status:

Have you ever been a smoker? Yes _____ / No _____ ☐

At what age did you start? _____ ☐☐

At what age did you quit? _____ ☐☐
(If currently smoking put '99')

Average packs/day _____ ☐☐

Pack-years _____ ☐☐

14. Swimmer: How long ago was it that you became a regular swimmer in this pool? ___ years &/or ___ months ago ☐☐☐

Worker: How long ago was it that you started to work regularly in this facility? ___ years &/or ___ months ago ☐☐☐

15. Why do you come to this particular pool/facility? ☐

Specify: ______________________________
(team, live nearby, work here, etc.)

16. In addition to this pool facility, do you also regularly use/work at another indoor _____ / outdoor _____ ☐

swimming pool? Yes ____ / No ____ ☐

If yes, why? ______________________________ ☐

If yes, which one? ______________________________ ☐

Which pool do you prefer? ☐

This one _______/Other one _______

Neither _______/Both OK _______

Comment: ______________________________ ☐

____

17. What pool did you use/work for on a regular basis before this pool? Specify (name): ____________________ ☐

and for how long _____ years &/or _____ months ☐☐☐

How long ago was this? ____ years &/or ____ months ☐☐☐

18. Why did you stop using/working at the previous pool? ☐

Specify reason: ______________________________
(eg. moved house, changed teams, laid off, etc.)

19. How often have you used/worked at this present facility over the past year? Please tell me the average number of times/week and the usual time of day that you were in the pool.

			Avg # times/week	Usual Time: Opening-11:59 a.m.=1 12:00 (noon)-4:59 p.m.=2 5:00-6:59 p.m.=3 7:00-Closing=4	
1989	June	SUM			☐☐
	July	SUM			☐☐
	Aug	SUM			☐☐
	Sept	FALL			☐☐
	Oct	FALL			☐☐
	Nov	WIN			☐☐
	Dec	WIN			☐☐
1990	Jan	WIN			☐☐
	Feb	WIN			☐☐
	Mar	WIN			☐☐
	Apr	SPR			☐☐
	May	SPR			☐☐
	June	SUM			☐☐
	July	SUM			☐☐

Specify reason if fluctuations from season-to-season: ☐

____

____

SWIMMING BEHAVIOUR/WORK PATTERNS OF FACILITY STAFF

20. Please tell me about the last time you swam in this pool.

On which day was it? ______________ (date) ☐☐☐☐
Month/Day

For how long were you in the water? _____ minutes ☐☐☐

At what time of the day did you get into the water?

______ a.m./p.m. ☐☐☐☐

21. On average over the past year, how long do you spend:
- in the facility before actually swimming? _____ min. ☐☐☐
- in the pool itself? _____ minutes, ☐☐☐
- in the facility after you complete your swim? _____ min. ☐☐☐
- Therefore, you spend _____ minutes in the facility? ☐☐☐

22. How often do you wear contact lenses when you swim/work?
0% ______ ☐
1-10% ______ ☐
11-30% ______ ☐
31-100% ______ ☐

23. How often do you wear protective eye goggles when you swim?
0% ______ ☐
1-10% ______ ☐
11-30% ______ ☐
31-100% ______ ☐

24. When using this facility, do you usually
- Swim lengths: Yes ____ / No ____ ☐
If yes, how many? _____ lengths ☐☐☐
distance per length ______ ☐☐
- Dive from the board(s): Yes ____ / No ____ ☐
If yes, from what height? _____ meters ☐☐
- Use saunas: Yes ____ / No ____ ☐
- Use hot tubs: Yes ____ / No ____ ☐
- Use steam rooms: Yes ____ / No ____ ☐
- Use only one, or more than one, of the pools
in the facility: One ____ / Two or more ____ ☐
Which one(s)? (specify): __________________ ☐
____
- Use the showers: Yes ____ / No ____ ☐

- Use the facility soap to wash your body in the shower? ☐
  Yes ____ / No ____
- Use the facility soap to wash you hair in the shower? ☐
  Yes ____ / No ____
- Use the vending (food) area? ☐
  Yes ____ / No ____
- Other (specify): ______________________________ ☐

25. When you are swimming/working here, how many people are usually in the pool? ____ ☐
Specify: (eg. zero, one, it varies from n_1 to n_2, etc.)

26. When you swim, do you usually swallow any pool water? Yes ____ / No ____ ☐
If yes, how many times? ____ ☐

✓

27. Effects of swimming/working in the facility.   Initials: ____________

I am now going to ask you some questions about health problems you may have at 5 specific time periods: before swimming, during swimming, immediately after swimming, immediately after leaving the facility, and about 6 hours after leaving the facility. I'll mention in sequence 11 symptoms. Could you please tell me how frequent and how severe the symptoms are, according to this card. Let me explain all 8 items to you.

Frequency	Severity
Never(N) = 0% of time	None(N) = no discomfort
Rarely(R) = ≤10% of time	Little(L) = uncomfortable
Sometimes(S) = 11-30% of time	Moderate(M) = hurts but you can still perform activity
Often(O) = >30% of time	Serious(S) = hurts and is so bad that your performance is seriously affected or you must stop the activity altogether

		Before Swimming		During Swimming		Immediately After Swimming		Immediately After Leaving Facility		About 6 Hours After Leaving Facility		
	Do you feel ...	Frequency	Severity	Frequency	Severity	Frequency	Severity	Frequency	Severity	Frequency	Severity	
1	well/fit		N/A		N/A		N/A		N/A		N/A	☐☐☐☐☐☐☐☐☐☐
2	dehydrated/thirsty											☐☐☐☐☐☐☐☐☐☐
3	weak/tired/ exhausted											☐☐☐☐☐☐☐☐☐☐
4	nauseous/like throwing up											☐☐☐☐☐☐☐☐☐☐
5	headache/dizziness											☐☐☐☐☐☐☐☐☐☐
6	skin itch/burns											☐☐☐☐☐☐☐☐☐☐
7	eye problems, eg: eye itch/redness/ tearing eyes											☐☐☐☐☐☐☐☐☐☐
8	sore ear(s)											☐☐☐☐☐☐☐☐☐☐
9	sore/irritated throat											☐☐☐☐☐☐☐☐☐☐
10	coughing/sneezing											☐☐☐☐☐☐☐☐☐☐
11	breathing difficulty, eg: asthma/ wheezing/tight chest/ SOB/choking											☐☐☐☐☐☐☐☐☐☐
12	other (specify):											☐☐☐☐☐☐☐☐☐☐

Comment ____ ☐

____

____

____

____

____

28. We want to see if your symptoms change from one swim/work day to another. From the list, do you notice a change in symptoms with a change in:

- indoor air temperature Yes ____ / No ____ ☐

  If yes, list symptom(s) affected: ________________ ☐
- pool water temperature Yes ____ / No ____ ☐

  If yes, list symptom(s) affected: ________________ ☐
- indoor air smell/odour/heaviness Yes ____ / No ____ ☐

  If yes, list symptom(s) affected: ________________ ☐
- the number of other pool users Yes ____ / No ____ ☐

  If yes, list symptom(s) affected: ________________ ☐
- indoor humidity Yes ____ / No ____ ☐

  If yes, list symptom(s) affected: ________________ ☐
- outdoor weather (e.g if raining) Yes ____ / No ____ ☐

  If yes, list symptom(s) affected: ________________ ☐
- time of year: Yes ____ /No ____ ☐

  winter/spring/summer/fall ☐

  If yes, list symptom(s) affected: ________________ ☐

Is there anything else that may affect your symptoms? ☐

____ ☐

Comment: ______________________________________

____

____

29. Did the moderate or serious symptoms arise before/after you started using/working in this facility?

Symptom	Before/After	
____________________	__________	☐☐
____________________	__________	☐☐
____________________	__________	☐☐
____________________	__________	☐☐
____________________	__________	☐☐
____________________	__________	☐☐

30. What do you think is the cause(s) of any of the problems noted in q. 27 above? Please specify: ☐☐

____

____

____

____

31. Are you satisfied with the swimming/work experience at this pool/facility? Yes ____ / No ____ ☐

Please explain: ______________________ ☐☐

____

____

____

____

32. Have you had to see a doctor in the past year or so about any of the symptoms noted in q. 27 above?

Yes ____ / No ____ ☐

For which symptom(s)? ________________ ☐

If yes, may we contact your doctor?

Yes ____ / No ____ ☐

Note: If respondent is under 18 years of age, parental consent must be obtained (see medical records release form).*

If yes, Name of Doctor: ________________ ☐☐☐

Address: ________________________

____

____

Date doctor was last seen for a facility-related complaint? ☐☐☐☐

____

month/year

*Parent/guardian name: ______________________

Address: ______________________________

____

______________________ Postal Code__________

Phone number:___________________________

33. Do you know personally anyone who uses or has used this facility and who has experienced moderate or serious symptoms from the list of symptoms/illnesses noted in q. 27 above? Yes ____ / No ____ ☐

- If yes, how many such people do you know? # _____ ☐☐

- How many of these could you ask to call us so that we could arrange to interview them? # ________ ☐☐

- Would you please try your best to ask all of these to contact us? Yes ____ / No ____ ☐

(If yes) Please be sure that they give us only your initials when they call us. Here is a card for each one of these people with a space for your initials on it, and also with our name and the telephone number for them to call.

34. Is there anything about your swimming/working experience here that you would like to tell me? I may not have asked you about everything. (This section is for any additional comments that are not provided for in the body of the questionnaire.) ☐

____
____
____
____
____
____
____
____
____
____
____
____
____
____
____

Check for initials on pages 1 and 7.

35. Interviewer: Please note how 'comfortable' the interviewee was through the interview: ☐

____

(anxious; seemed credible; honest; comfortable; not good; etc.)

INFORMED CONSENT DOCUMENT

TITLE:

A Health Survey of Public Pool Users

INVESTIGATOR(S):

Dr. Colin L. Soskolne and Dr. Steve E. Hrudey
Faculty of Medicine
University of Alberta

INFORMATION:

We are studying pool users and staff at a number of Alberta public swimming pools to find out how much and why they use these pools. We also want to know if there are any health problems that people have when using the swimming pools. We want to know for how long any kind of health problem has existed and/or for how long it would last after you have used the pool; muscles, skin, eyes, chest/breathing or other parts of the body may be considered. Your participation is voluntary and will involve answering questions which should take about 40 minutes of your time.

Your answers will be stored anonymously. All personal information is confidential to this study. Results will be reported using an average of all the people who are interviewed. In this way, a single person cannot be identified. You can stop the interview at any time you want without any harm to your pool use, job or position on the team, etc. The interviewer will try to answer any questions you may have. However, if you have any questions about your health it may be necessary for us to refer you to a doctor. Would you be willing to help us by answering the questions?

CONSENT:

I understand that the interview process described above, of which I have a copy, has been explained to me, and that any questions that I have asked have been answered to my satisfaction. I know that I may contact Dr. C.L. Soskolne (492-6013) if I have further questions either now or in the future. I have been told that this interview is voluntary. I understand the possible benefits of joining the research study, and that no known risks are involved. I have been told that personal records relating to this study will be kept confidential. I understand that I am free to withdraw from the study at any time. I understand that the participation required of me is limited to a single interview lasting about 40 minutes.

____
(Initials only, for reasons of anonymity)

The person who may be contacted
about the research is:

Dr. C. L. Soskolne

Telephone No. 492-6013

____
(Signature of Witness)

____
(Date)

____
(Signature of investigator or designee)

MEDICAL RECORDS RELEASE AUTHORIZATION

I hereby authorize Dr. ______________________________

Address: ______________________________

____

____

to release all medical information from the file of ____________________
(Name)

relating to any swimming pool complaint (s) to

Dr. Colin Soskolne
University of Alberta
13-103 Clinical Sciences Bldg.
Edmonton, Alberta T6G 2G3

NB: If subject is less than 18 years of age, consent must be obtained from the parent/guardian.

______________________ (Signature - Facility User)	______________________ (Printed Name)
______________________ (Witness)	______________________ (Date)
______________________ (Signature - Parent/Guardian)	______________________ (Printed Name)
______________________ (Witness)	______________________ (Date)

INFORMED CONSENT DOCUMENT

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A Health Survey of Public Pool Users

INVESTIGATOR(S):

Dr. Colin L. Soskolne and Dr. Steve E. Hrudey
Faculty of Medicine
University of Alberta

INFORMATION:

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CONSENT:

I understand that the interview process described above, of which I have a copy, has been explained to me, and that any questions that I have asked have been answered to my satisfaction. I know that I may contact Dr. C.L. Soskolne (492-6013) if I have further questions either now or in the future. I have been told that this interview is voluntary. I understand the possible benefits of joining the research study, and that no known risks are involved. I have been told that personal records relating to this study will be kept confidential. I understand that I am free to withdraw from the study at any time. I understand that the participation required of me is limited to a single interview lasting about 40 minutes.

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(Initials only, for reasons of anonymity)

The person who may be contacted
about the research is:

Dr. C. L. Soskolne

Telephone No. 492-6013

____
(Signature of Witness)

____
(Date)

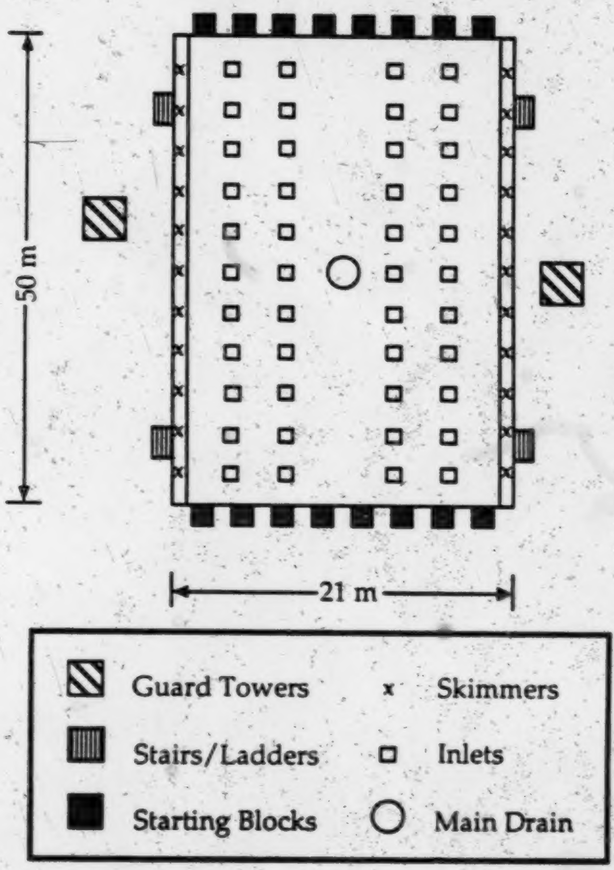
____
(Signature of investigator or designee)

APPENDIX B

General Information on Swimming Pools, Management Practices and Ventilation

Identification code: Swimming Pool Facility: Pool I
Individual Tank (or Part of Tank): A

Sizing: Shape description (drawing)


50 m
21 m
Guard Towers
Skimmers
Stairs/Ladders
Inlets
Starting Blocks
Main Drain

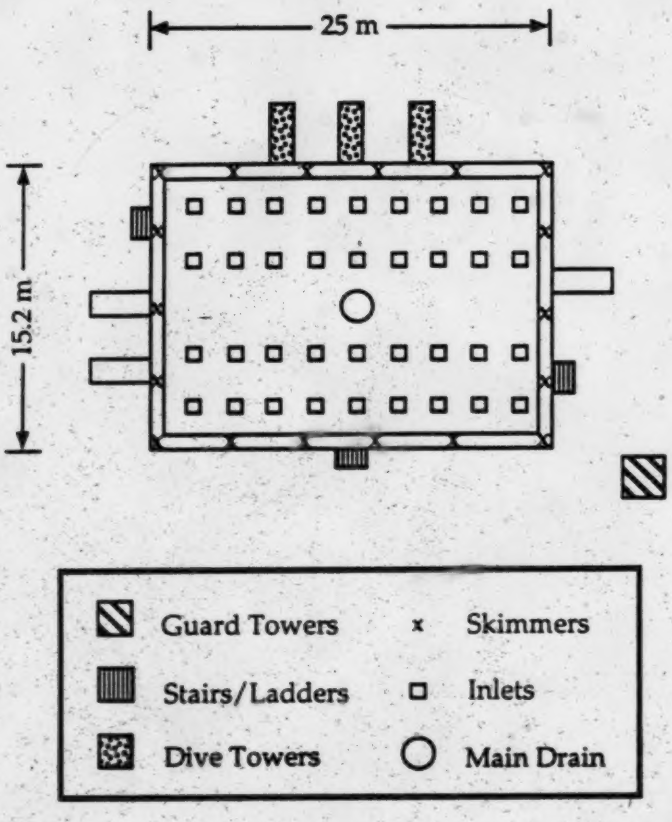
Width: 21 m
Length: 50 m
Depth: 2.0 to 2.3 m
Volume: 550 000 gal (2082 m^3)
Turn Over Rate: 5.5 h

Location and number of water inlets:
Consult diagram above (inlets):
4 rows of 11 inlets at the bottom, 4.67 m between each.

Location and number of water outlets:
Consult diagram above (skimmers & main drain):
11 skimmers on each sides (Length), 4.67 m between each.
One additional main drain, in the centre.

Identification code: Swimming Pool Facility: Pool I
Individual Tank (or Part of Tank): B

Sizing: Shape description (drawing)


25 m
15.2 m
Guard Towers
Stairs/Ladders
Dive Towers
Skimmers
Inlets
Main Drain

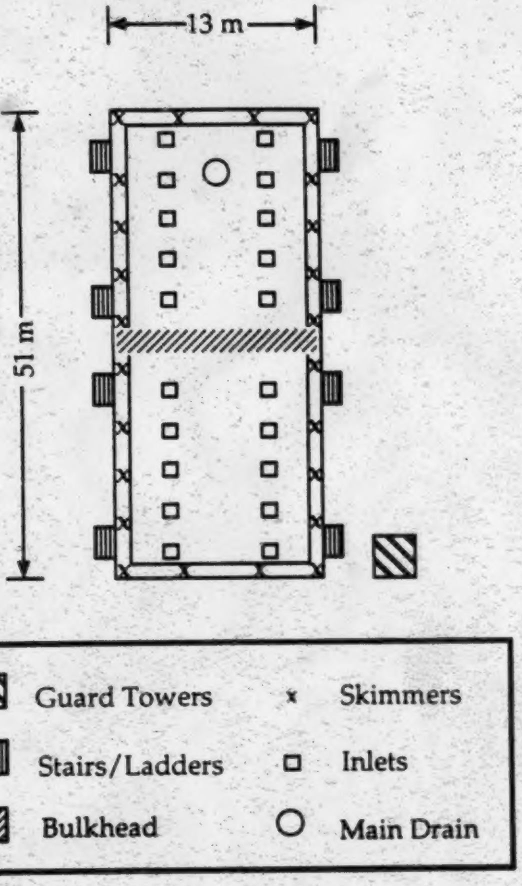
Width: 15.2 m
Length: 25 m
Depth: 4.9 m
Volume: 402 000 gal (1522 m^3)
Turn Over Rate: 4 to 5 h

Location and number of water inlets:
Consult diagram above (inlets)
4 rows of 11 inlets at the bottom, 4.67 m between each.

Location and number of water outlets:
Consult diagram above (skimmers & main drain)
18 skimmers distributed all around, 4.67 m between each.
One additional main drain, in the centre.

Identification code: Swimming Pool Facility: Pool I
Individual Tank (or Part of Tank): C & D

Sizing: Shape description (drawing)


13 m
51 m
Guard Towers
Skimmers
Stairs/Ladders
Inlets
Bulkhead
Main Drain

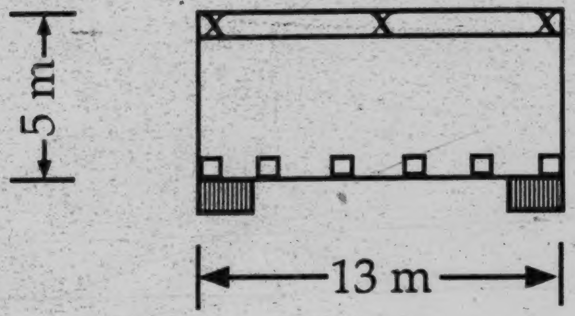
Width: 13 m
Length: 51 m (Bulkhead separating pool in two parts)
Depth: 1 m
Volume: 151 000 gal (572 m^3)
Turn Over Rate: 4 to 5 h

Location and number of water inlets:
Consult diagram above (inlets)
2 rows of 12 inlets at the bottom, 16 ft between each.

Location and number of water outlets:
Consult diagram above (skimmers & main drain)
24 skimmers distributed all around, 14 ft between each.
One additional main drain, at the west end (Part C).

Identification code: Swimming Pool Facility: Pool I
Individual Tank (or Part of Tank): E

Sizing: Shape description (drawing)



▧	Guard Towers	x	Skimmers
▥	Stairs/Ladders	□	Inlets
▨	Bulkhead	○	Main Drain

Width: 5 m
Length: 13 m
Depth: 0.75 m
Volume: 10 000 gal (38 m^3)
Turn Over Rate: 50 min

Location and number of water inlets:
Consult diagram above (inlets)
10 inlets, 1.2 m between each.

Location and number of water outlets:
Consult diagram above (skimmers & main drain)
3 skimmers (West end), 2.5 m between each.
One additional main drain, in the centre.

Identification code: Swimming Pool Facility: Pool I

Disinfection chemical(s) used: Chlorine gas

suppliers (lot numbers): Stanchem Lot #: UN 1017
Stock #: 5000-4366 7/89

normal rate of addition: When needed (anytime Chlorine level drops below 2.0 ppm)

monitoring practices: Chemtrol computer water test, approximately every 4 hours (4 times daily). LSI's (Langelier Saturation Index), twice a week or more if needed.

Cleaning and maintenance practices:

schedule: Vacuumed weekly, pool drained and scrubbed once a year. Pool filters are hosed and new diatomaceous earth applied when vacuum pressure rises above 10. These filters are also removed and scrubbed once a year or earlier if needed.

cleaners used: ACIDEX Mackenzie and Fiemann Ltd.
Lot #: UN 1789

Identification code: Swimming Pool Facility: Pool I

Ventilation Information:

Location of air intakes: Outside of building, just below rode line.

Location of air returns: At present only one air return unit. Outlets at east end of aquatic centre approximately 40 ft above pool deck. only used if we are unable to maintain temperature in extreme cold.

Air circulation rate (range and typical values):
Three supply fans: from 0 to 34,500 CFM each
One supply fan: from 0 to 25,000 CFM.

Type of blower:

Type of filters: Synthetic

Filter maintenance protocol: On automatic rollers, changed as required. Frequency increases in the spring.

Climate controls:
Temperature (type of cooling): No cooling
(range and typical)

Humidity (type of humidity control): Supply air fans
(range and typical)

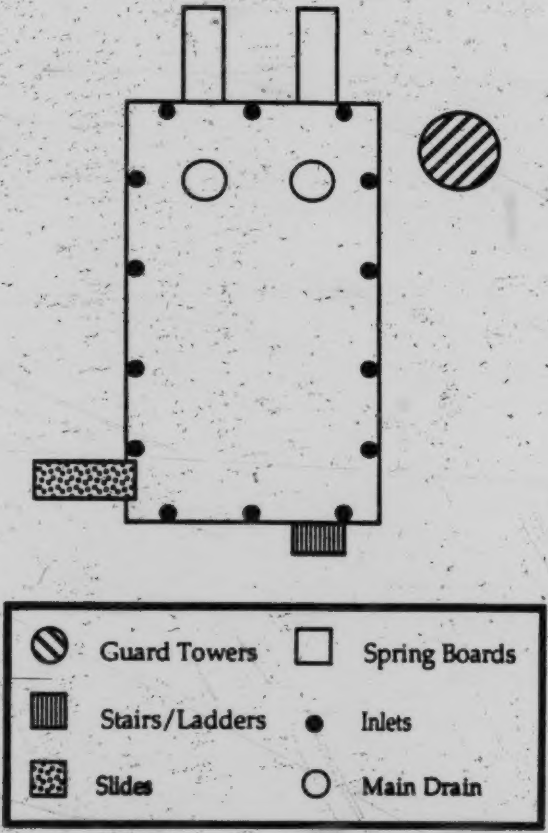
Typical control strategy: Air supply is controlled by relative humidity primarily; temperature is secondary.

Description of any studies which have been done on the ventilation system:

An engineering study was completed in 1988. As a result of the study, corrective measures have been instituted: 1) Filters changed from fibreglass to synthetic in May 1990; 2) Dehumidification unit being installed-July to September, 1990.

Identification code:	Swimming Pool Facility:	Pool II
	Individual Tank (or Part of Tank):	α

Sizing: Shape description (drawing)


Guard Towers
Spring Boards
Stairs/Ladders
Inlets
Slides
Main Drain

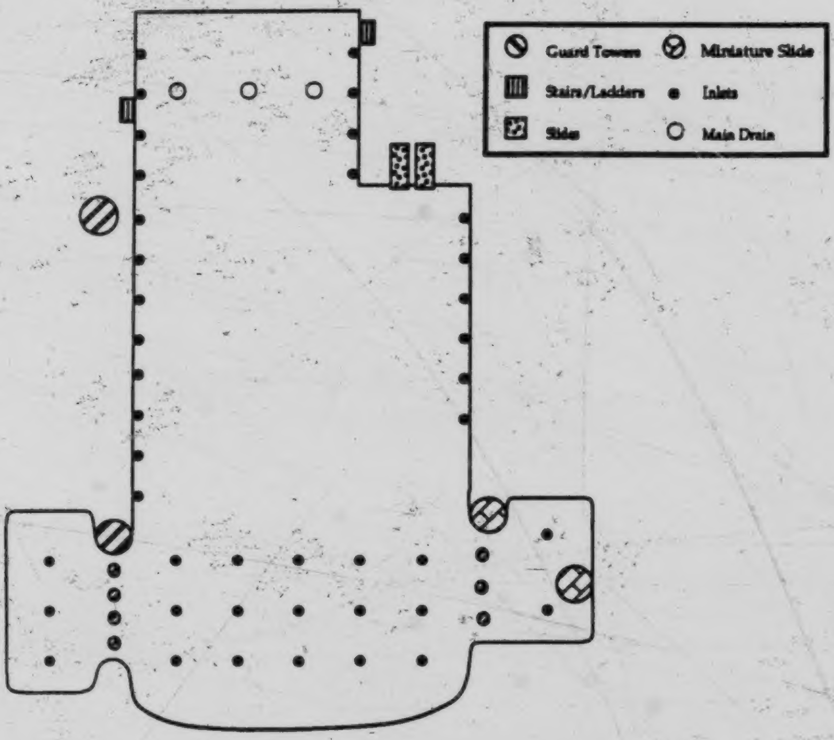
Width: 27 ft (8.2 m)
Length: 42 ft (12.8 m)
Depth: 12 ft (3.7 m)
Volume: 150,000 US gal (568 m^3)
Turn Over Rate: 5 to 6 h

Location and number of water inlets:
  Consult diagram above (inlets)
  14 inlets distributed all around.

Location and number of water outlets:
  Consult diagram above (skimmers & main drain)
  Two drains at the bottom.

Identification code: Swimming Pool Facility: Pool II
Individual Tank (or Part of Tank): β

Sizing: Shape description (drawing)


Guard Towers
Miniature Slide
Stairs/Ladders
Inlets
Slides
Main Drain

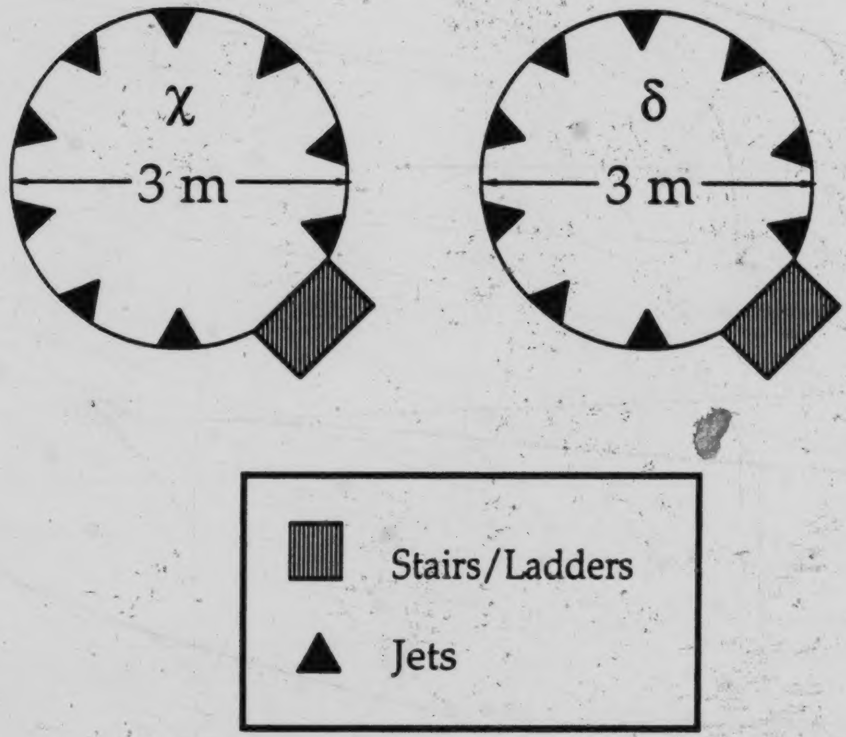
Width: 54 ft (16.5 m) in deep end, 82 ft (25 m) towards middle, 117 ft (35.6 m) at shallow end.
Length: 111 ft (33.8 m) with side walls, 36 ft (11 m) shallow end.
Depth: from 7 ft (2.1 m) to 6 inches (15 cm)
Volume: 350,000 US gal.
Turn Over Rate: 5 to 6 h

Location and number of water inlets:
Consult diagram above (inlets)
42 inlets distributed throughout.

Location and number of water outlets:
Consult diagram above (skimmers & main drain)
Three drains at the bottom, in the deep end.

Identification code: Swimming Pool Facility: Pool II
Individual Tank (or Part of Tank): χ & δ

Sizing: Shape description (drawing)



Diameter 10 ft (3 m)
Depth:
Volume: 3,000 US gal each.
Turn Over Rate: 10 min

Location and number of water inlets:
Consult diagram above (inlets)

Location and number of water outlets:
Consult diagram above (skimmers & main drain)

Identification code: Swimming Pool Facility: Pool II

Disinfection chemical(s) used: Chlorine gas (for α & β)
12% Sodium Hypochlorite (for χ & δ),
Oxibrite-GLB

suppliers (lot numbers):

normal rate of addition:

monitoring practices: Disinfecting agents feed in by metered pumps monitored by automated controller (Strantrol) water tests done 4 times a day.

Cleaning and maintenance practices: Backwash
Filter clause
Maintenance/Preventive
(Computer monitored)

schedule: Weekly rotational cleaning

cleaners used:

- -Oxiguard
- -TLC
- -Windex
- -Sunlight soap
- -Quata Bac
- -Comet

sequestrian agents:

- -Super Sequal Solution
- -Algmycin
- -Clarifier
- -Sodium Bicarbonate
- -Calcium Chloride

Identification code: Swimming Pool Facility: Pool II

Ventilation Information:

Location of air intakes: On the roof, some 200 ft West of pool area.

Location of air returns: Two return duck inlets on pool ceiling

Air circulation rate (range and typical values):

Type of blower: Two air handling units

Type of filters: do % efficiency, cardboard

Filter maintenance protocol: 0.5 inch of water

Climate controls:
Temperature (type of cooling): 30 to 32°C
(range and typical)

Humidity (type of humidity control): 35 to 45 % RH
(range and typical)

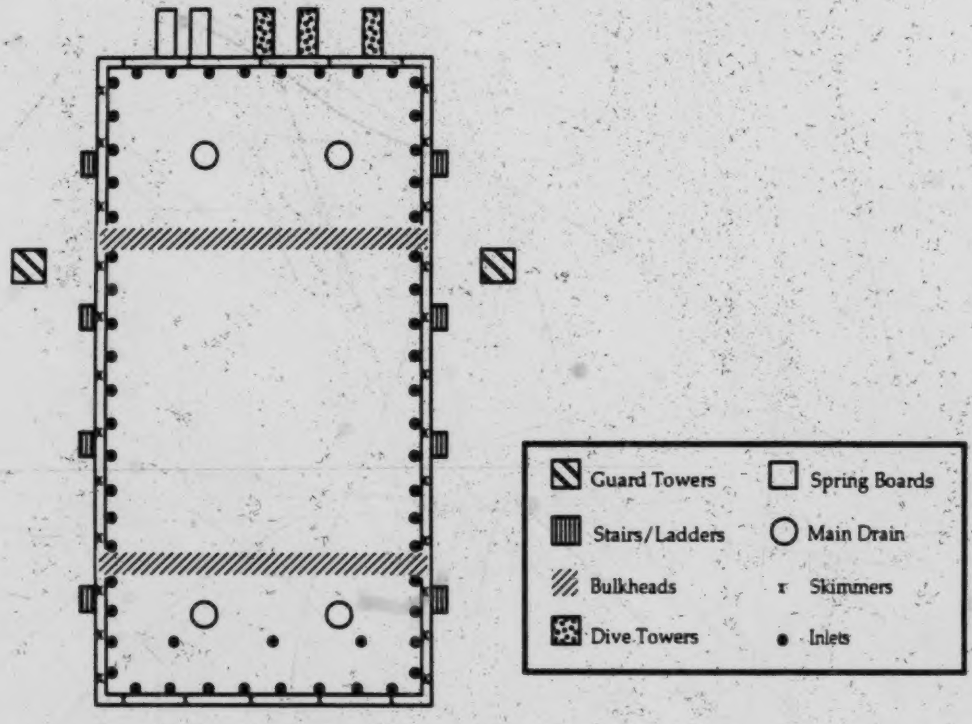
Typical control strategy: Fresh air dampers open as much as possible

Description of any studies which have been done on the ventilation system

-Air Balancing
-Smoke Tests
-Relocate Air Return
-Remove Diffuser
-Various Air Quality Studies

Identification code: Swimming Pool Facility: Pool III
Individual Tank (or Part of Tank): X, Y & Z

Sizing: Shape description (drawing)


Guard Towers
Spring Boards
Stairs/Ladders
Main Drain
Bulkheads
Skimmers
Dive Towers
Inlets

Width: 21 m
Length: 52 m
Depth: from 2.41 m to 4.5 m
Volume:
Turn Over Rate: 6.3 h

Location and number of water inlets:
- Consult diagram above (inlets)
- 52 inlets distributed all around (two different elevations)
- 3 inlets at the bottom (South end)

Location and number of water outlets:
- Consult diagram above (skimmers & main drain)
- Continuous skimmer all around (Sides and Ends)
- 4 additional main drains, 2 at each end

Identification code: Swimming Pool Facility: Pool III

Disinfection chemical(s) used: Chlorine gas

suppliers (lot numbers): Prairie Industrial Chemical

normal rate of addition: Maintain 1.5 ppm Free Chlorine

monitoring practices: Use Strantrol 390, computerized chemical controller (Controls pH as well)

Other chemicals added:
-Sodium Bicarbonate
-Sodium Hydroxide (7% solution)
-Muriatic Acid

Cleaning and maintenance practices:

schedule: Use auto vacuum daily (from 11 pm to 6 am, 7 days a week)

cleaners used: Sodium Hypochlorite 12%

Identification code: Swimming Pool Facility: Pool III

Ventilation Information:

Location of air intakes: Southside roof overhang.

Location of air returns: Southend upper pool space.

Air circulation rate (range and typical values): 40,000 CFM

Type of blower: Centrifugal

Type of filters: R

Filter maintenance protocol: 3 month auprale
Monitor static pressure weekly

Climate controls:
Temperature (type of cooling): Outdoor air
(range and typical): 15%

Humidity (type of humidity control): Outdoor air, Dry-Otron
(range and typical) 50% RH

Typical control strategy: Use outdoor air when temperature is above -10°C. Use Dry-Otron when temperature is bellow -10°C.

Description of any studies which have been done on the ventilation system

Dehumidification Cost Analysis and Modification Proposals by Engineering firm.

APPENDIX C

Summary of
Alberta Regulation 247/85
Public Health Act
Swimming Pool Regulation

Table C.1 Summary of "Swimming Pool Regulation" Under the Public Health Act, Applicable to Public and Semi-Public Swimming Pools.

Licence holder under Public Health Act for Swimming Pool must provide or oblige by the following:

-competent and responsible swimming pool operator supervising swimming pool operation, water chemistry and maintenance.

-circulation system and chemical feeders under continuous operation except: stoppage for maintenance, repairs or backwashing of filters, or during swimming competition.

-except during competition no person shall use the swimming pool when circulation system is not operating.

-swimming pool shall be operated so that no less than 50% of circulated water is returned through overflow devices or channels.

-swimming pool design to waste overflow shall operate under conditions such that no less than 10 % of circulated water passes through overflow devices or channels.

-all equipment shall be maintained in good working order: gauges, flow meters, thermometers, filters, pumps, disinfection equipment.

-swimming pool shall be provided with continuous disinfection when in use.

-method of disinfection shall be chlorination.

-swimming pool shall be provided with adequate testing equipment to measure chlorine residuals.

-measuring equipment must be capable of measuring free chlorine residuals and combined chlorine residuals separately.

-testing equipment must provide a range of 0 to 5.0 mg of Cl/L for swimming pool other than whirlpool, and of 0 to 10 mg of Cl/L for whirlpool.

-free chlorine tests shall be performed as often as necessary under normal hour of operation to permit operator to maintain the free chlorine residual at levels permitted by this section, and in no case shall test be performed at intervals of more than 4 h.

Table C.1 Summary of "Swimming Pool Regulation" Under the Public Health Act, Applicable to Public and Semi-Public Swimming Pools. (continued)

-free chlorine residuals level shall be sufficient to maintain pool water in a bacteriological and chemical safe conditions at all time, and in no case shall the level be less then:

-0.5 mg Cl/L in any swimming pool with an operating temperature of not more than 30 °C, and
-1.0 mg Cl/L in any swimming pool with an operating temperature of more than 30 °C.

-test for combined chlorine residuals shall be conducted at least every 7 days.

-if on any test the combined chlorine residual is greater than 1.0 mg/L, the pool shall forthwith be treated to lower it below that level.

-swimming pool shall be provided with equipment to measure pH.

-pH testing equipment shall have a range of 6.8 to 8.2.

-pH tests shall be performed as often as necessary under normal hour of operation to permit operator to maintain the pH at levels permitted by this section, and in no case shall test be performed at intervals of more than 4 hrs.

-pH shall be maintained at no less than 7.2 and no more than 8.0.

-where swimming pool is equipment with automated chemical monitoring and feeding equipment, a manual test for free chlorine residuals and pH shall be conducted at least every 24 hrs.

-at least 1 bacteriological sample of swimming pool water shall be taken at intervals of not more than 7 days, and shall be submitted to the Provincial Laboratory of Public Health for examination.

-samples shall be collected while the swimming pool is in use and shall be taken from a point near an outlet for no other reasons than to give an accurate representation of the swimming pool water.

-samples of chlorinated water shall be dechlorinated before being send to the Provincial Laboratory of Public Health.

Table C.1 Summary of "Swimming Pool Regulation" Under the Public Health Act, Applicable to Public and Semi-Public Swimming Pools. (continued)

-water quality shall be maintained so that not more than 2 consecutive water samples and not more than 15% of the series of samples taken over a 6 month period

- -contained more than 200 bacteria/mL, as determined by standard 35°C plate count;
- -show the presence of Pseudomonas aeruginosa, in the case of a swimming pool maintained at a temperature of greater than 30°C, or
- -show:
  - -a positive test for coliform organisms in any of the five 10 mL portions of a sample when that test methods is used, or
  - -the presence of coliform organisms in 100 mL when the membrane filter test is used.

-operating records showing the following informations shall be maintained:

- -quantities and dates of all chemical used;
- -time and results of all pH test taken;
- -time and results of all free chlorine residual test taken;
- -time and results of all combined chlorine residual test taken;
- -results of bacteriological analyses;
- -temperature of the water, recorded at least once every 24 hrs.;
- -result of any other test that may be taken from time to time.

-operating records shall be made available on request to an executive officer.

-water in a filled swimming pool shall be sufficiently clear to enable identification of the pattern of the drain in the deep end by a person standing on the edge of the pool, or identification of a 150 mm black disk on a white background position in the deepest part of the pool by a person standing 9 m away from the disk.

-visible dirt on the bottom of a swimming pool shall not be permitted to remain more than 24 hrs.

-when a nuisance exists in a swimming pool

- -because of lack of clarity of the pool water, or
- -because of the presence of unsanitary or injurious material in the pool or on the deck,
  - -the owner shall direct all persons to leave the pool or any part of the pool until the nuisance is abated.

Table C.1 Summary of "Swimming Pool Regulation" Under the Public Health Act, Applicable to Public and Semi-Public Swimming Pools. (continued)

-swimming pool shall be secured from public access at other time than operating hrs.

-number of persons permitted in whirlpool or special purpose pool, at any one time shall not be more than
  -1 person per square meter, and
  -the maximum design bathing load.

-number of persons permitted in a swimming pool, other than whirlpool or special purpose pool, at any one time shall not be more than
  -1 person per 1.5 square meter, and
  -the maximum design bathing load.

-maximum number of persons permitted to use recreational water slides flumes an a water park theme shall not exceed the maximum design bathing load as specified in the application for licence.

-notice referred to in that subsection shall be posted, without restriction to the generality described in the above sections
  -maximum number of persons permitted to use the swimming pool at any one time
  -requirement that persons using swimming pool take shower before entering the pool area
  -statement that persons with communicable disease or communicable infection are not permitted to use the pool
  -statement that spiting in, spouting water in, blowing the nose in, urinating in or otherwise polluting the water is prohibited

-owner shall restrict admittance from swimming pool to any persons
  -with reason to believe they have a communicable disease or infection
  -with unclean appearance

-no person shall
  -use a swimming pool if he has a communicable disease of infection
  -spit, spout water in , blow his nose, urinate in or otherwise pollute the water in the swimming pool

-soap must be available in the showers at all time

-dressing room floors, furnishing and sanitary equipment in them, as well as pool decks and walkways shall be maintained in a clean sanitary condition

Table C.1 Summary of "Swimming Pool Regulation" Under the Public Health Act, Applicable to Public and Semi-Public Swimming Pools. (continued)

-use of canvas or other fibrous adsorptive matting is prohibited where people will be walking bear feet

-furniture used in dressing rooms and pool decks shall be impervious, durable and washable material

-food concession are prohibited unless there is a clear area reserved for that purpose

-The Swimming Pool Regulations (Alta. Reg. 39/73) and the Clean Water Authority Designation Regulations (Alta. Reg. 200/77) are repealed

APPENDIX D

Chemical Analysis Results

APPENDIX D1

Aldehydes

APPENDIX D1.1

NIOSH 4501 Formaldehyde Standardization

APPENDIX D1.1 NIOSH 4501 Formaldehyde Standardization

Formaldehyde as the formalin 37% solution was standardized by the NIOSH 4501 method. Sulfuric acid 0.0202 N was used, it was not necessary to use sodium hydroxide (as a base) because the initial pH was higher than the recommended range, pH 7 to 9. The correction was performed with the sulfuric acid solution. The concentration for the formalin solution is obtained with the following equation taking into account the 17.9 to 1000 dilution factor and the formalin density 1.083 g/mL.

$$C_s = \frac{30.0 \times [(N_a \times V_a) - (N_b \times V_b)]}{V_s} \times \frac{1000}{17.9} \times \frac{1}{1.083} \qquad \text{in g/kg}$$

where: C_s = concentration of the Formalin stock solution
30.0 = 30.0 g/equivalent of Formalin
N_a = normality of sulfuric acid, 0.0202 N H_2SO_4
V_a = volume (mL) of sulfuric acid use for titration
N_b = normality of sodium hydroxide
V_b = volume (mL) of sodium hydroxide use for titration
V_s = volume of formalin solution used in titration (2.00 mL).

Table D1.1.1 Formalin Standardization with 0.0202 N Sulfuric Acid.

Volume of Acid Added	**Concentration of Formalin**	**Concentration of Formalin**
mL	**g/kg**	**% w/w**
23.83	372.46	37.25
23.81	372.15	37.22
23.83	372.46	37.25
23.75	371.21	37.12
23.83	372.46	37.25
23.71	370.59	37.06

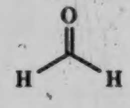
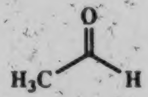
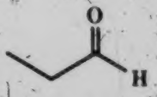
Average Concentration of Formalin	**Average Concentration of Formalin**
g/kg	**% w/w**
371.9 ± 0.8	37.19 ± 0.08

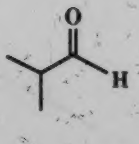
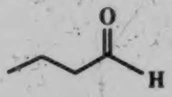
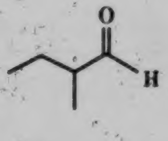
APPENDIX D1.2

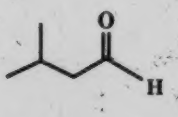
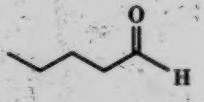
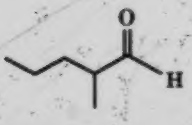
Aldehydes Information and Retention Times

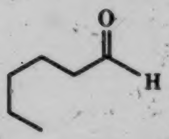
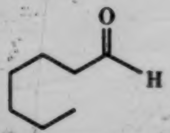
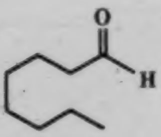
APPENDIX D1.2 Aldehydes Information and Retention Times Aldehydes

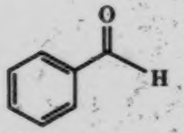
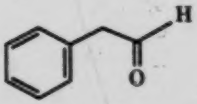
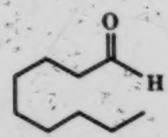
The retention times (R.T.) for the aldehydes for which calibration curves were performed are given hereafter along with other informations about each aldehydes. The solubility is given in units of g of aldehyde/100 g of water.

Name:	**Formaldehyde**	**Acetaldehyde**	**Propionaldehyde**
			
	$HCHO$	CH_3CHO	CH_3CH_2CHO
F.W.:	30.03	44.05	58.08
m.p.:	-92°C	-121°C	-81°C
b.p.:	-21°C	21°C	46-50°C
Density:	1.083 @ 37%w/w	0.788	0.805
Solubility:	v sol	∞	16
CAS #:	[50-00-0]	[75-07-0]	[123-38-6]
R.T.:	5.58	7.32/7.50	9.12/9.25

Name:	**Isobutanal**	**Butanal**	**2-Methylbutanal**
			
	$(CH_3)_2CHCHO$	$CH_3CH_2CH_2CHO$	$CH_3CH_2CH(CH_3)CHO$
F.W.:	72.11	72.11	86.13
m.p.:	-65.9°C	-99°C	
b.p.:	63°C	75°C	90-92°C
Density:	0.794	0.817	0.804
Solubility:	11	7	
CAS #:	[78-84-2]	[123-72-8]	[96-17-5]
R.T.:	9.92	10.80/10.94	11.65

Name:	Isovaleraldehyde	Valeraldehyde or Pentanal	2-Methylvaler-aldehyde
			
	$(CH_3)_2CHCH_2CHO$	$CH_3(CH_2)_3CHO$	$CH_3(CH_2)_2CH(CH_3)CHO$
F.W.:	86.13	86.13	100.16
m.p.:	-51°C	-91°C	
b.p.:	90°C	103°C	119-120°C
Density:	0.803	0.810	0.808
Solubility:	sl s	sl s	
CAS #:	[590-86-3]	[110-62-3]	[123-15-9]
R.T.:	11.81	12.48/12.60	13.04

Name:	Hexanal	Heptanal	Octanal
			
	$CH_3(CH_2)_3CHO$	$CH_3(CH_2)_5CHO$	$CH_3(CH_2)_6CHO$
F.W.:	100.16	114.19	128.22
m.p.:	-56°C	-42°C	
b.p.:	131°C	153°C	171°C
Density:	0.834	0.850	0.821
Solubility:	sl s	0.1	sl s
CAS #:	[66-25-1]	[111-71-7]	[124-13-0]
R.T.:	14.14	15.52	16.84

Name:	Benzaldehyde	Phenylacetaldehyde	Nonanal
			
	C_6H_5CHO	$C_6H_5CH_2CHO$	$CH_3(CH_2)_7CHO$
F.W.:	106.12	120.15	142.24
m.p.:	-26°C		
b.p.:	178-179°C	195°C	185°C
Density:	0.1.044	1.027	0.827
Solubility:	0.3		
CAS #:	[100-52-7]		[124-19-6]
R.T.:	17.12	17.72/17.84	18.07

APPENDIX D1.3

Aldehydes Calibration Curves

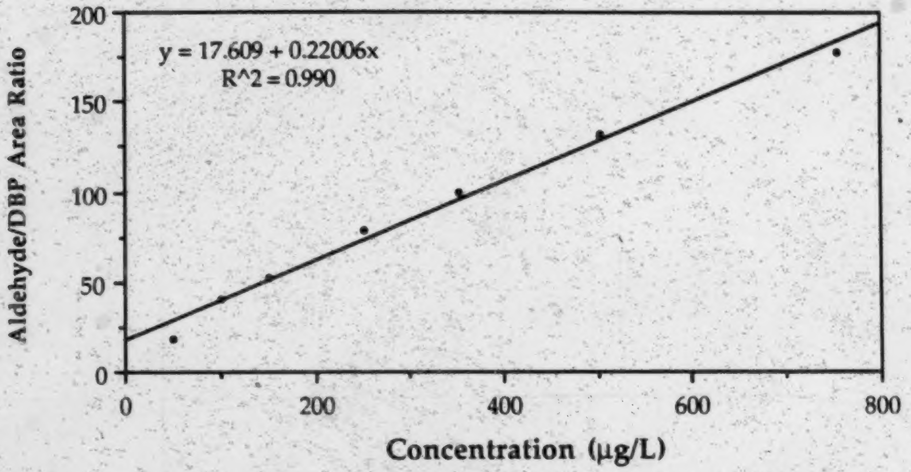


Figure D1.3.1 Formaldehyde Calibration Curve-July 15, 1990.

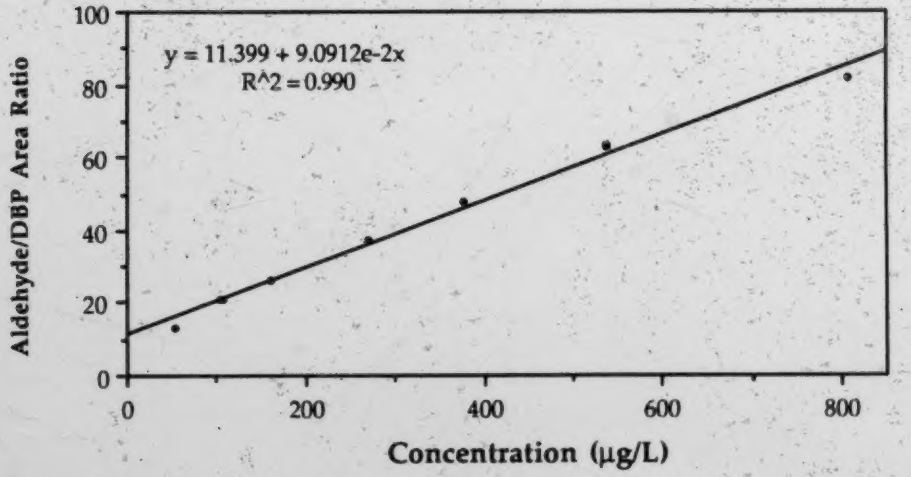


Figure D1.3.2 Acetaldehyde Calibration Curve-July 15, 1990.

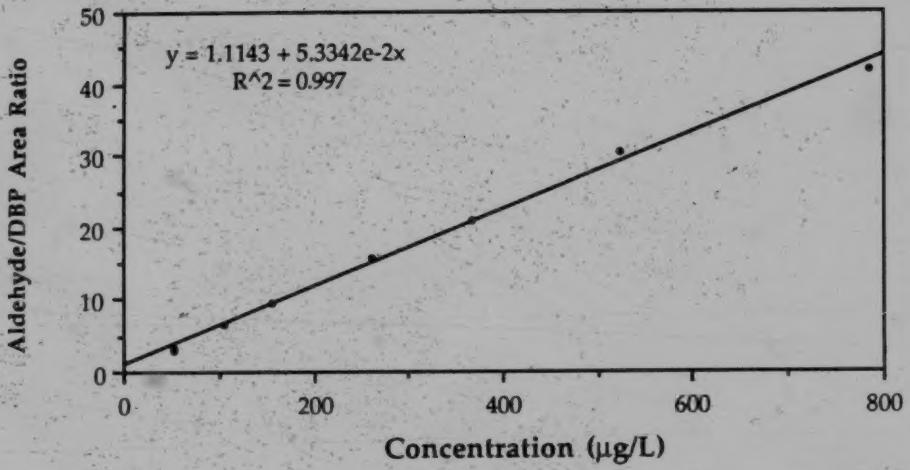


Figure D1.3.3 Propionaldehyde Calibration Curve-July 15, 1990.

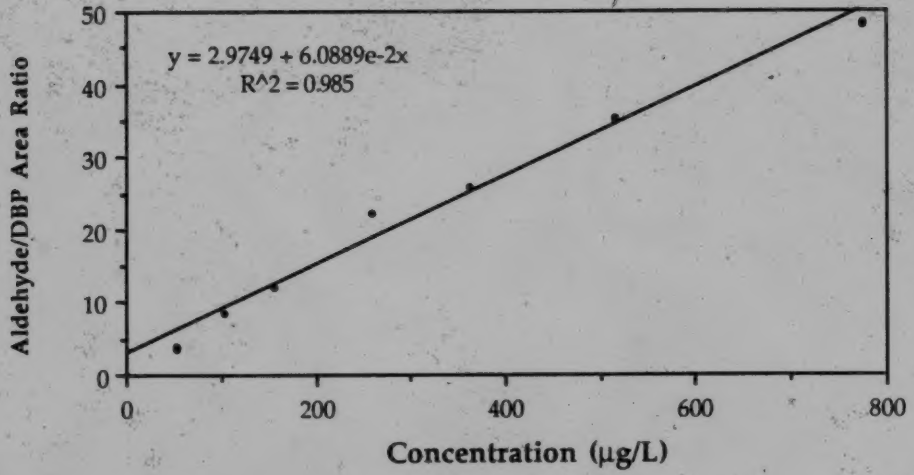


Figure D1.3.4 Isobutanal Calibration Curve-July 15, 1990.

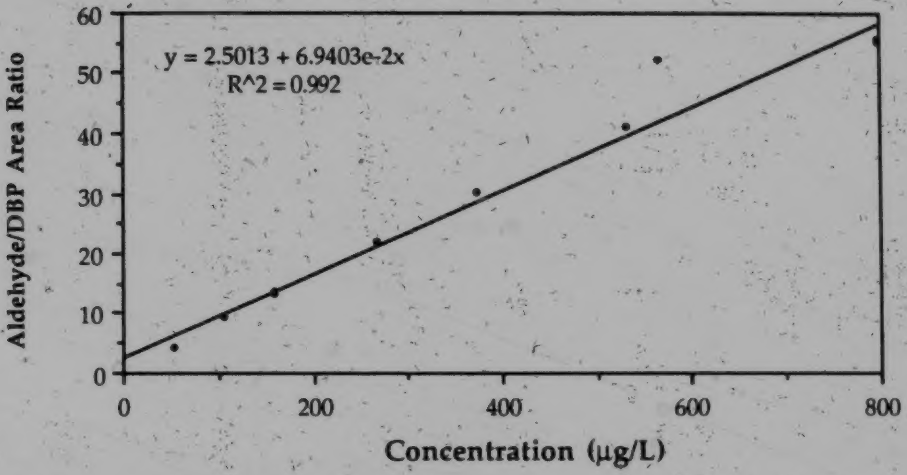


Figure D1.3.5 Butanal Calibration Curve-July 15, 1990.

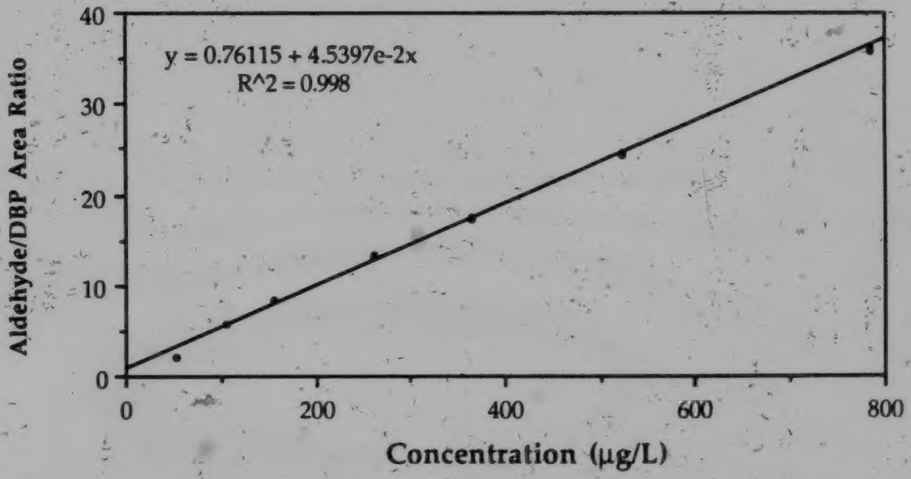


Figure D1.3.6 2-Methylbutanal Calibration Curve-July 15, 1990.

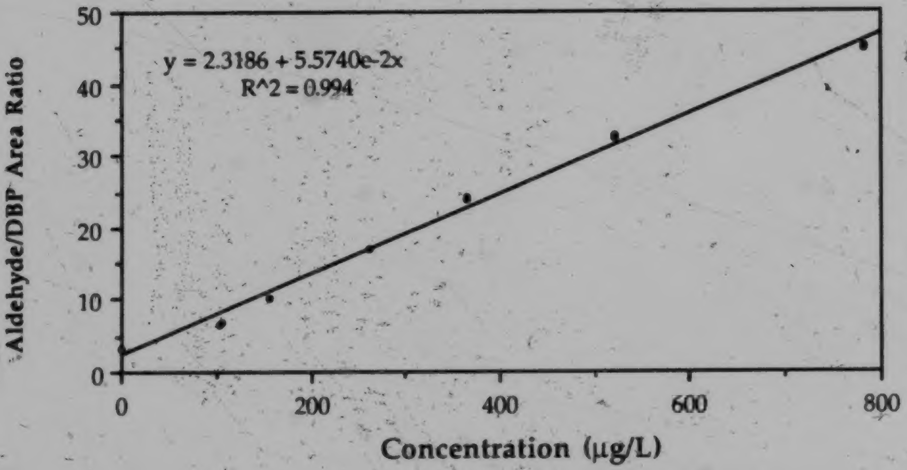


Figure D1.3.7 Isovaleraldehyde Calibration Curve-July 15, 1990.

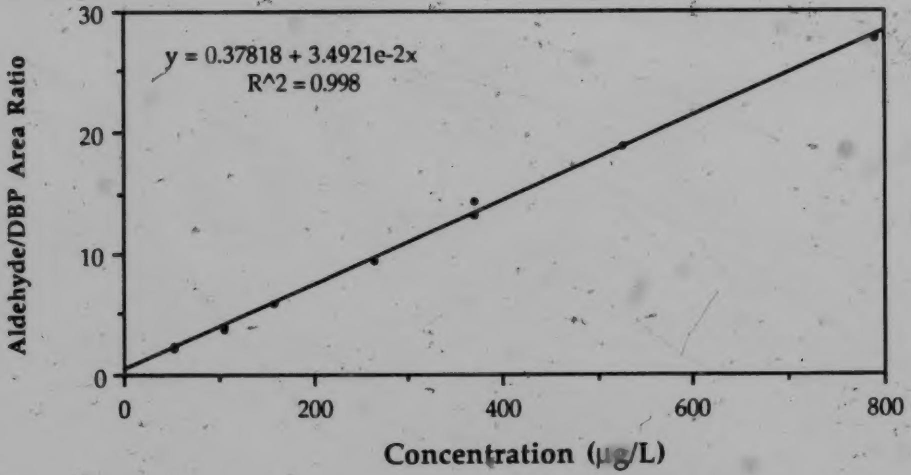


Figure D1.3.8 Valeraldehyde or Pentanal Calibration Curve-July 15, 1990.

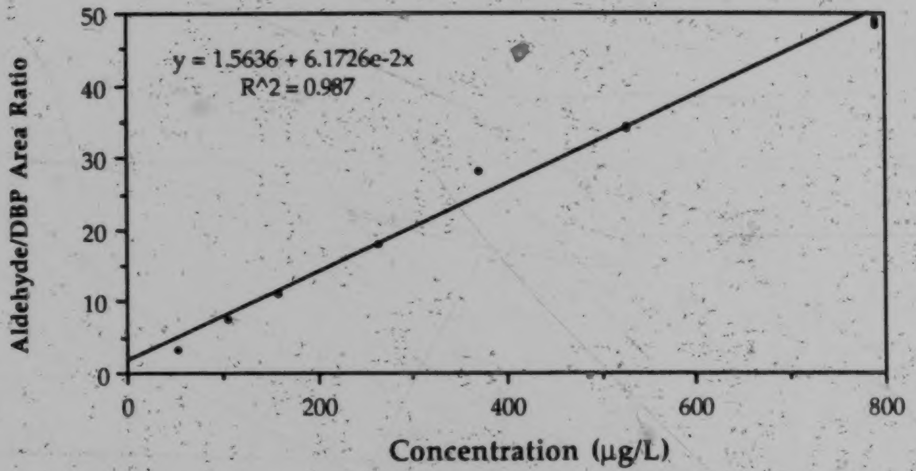


Figure D1.3.9 - 2-Methylvaleraldehyde Calibration Curve-July 15, 1990.

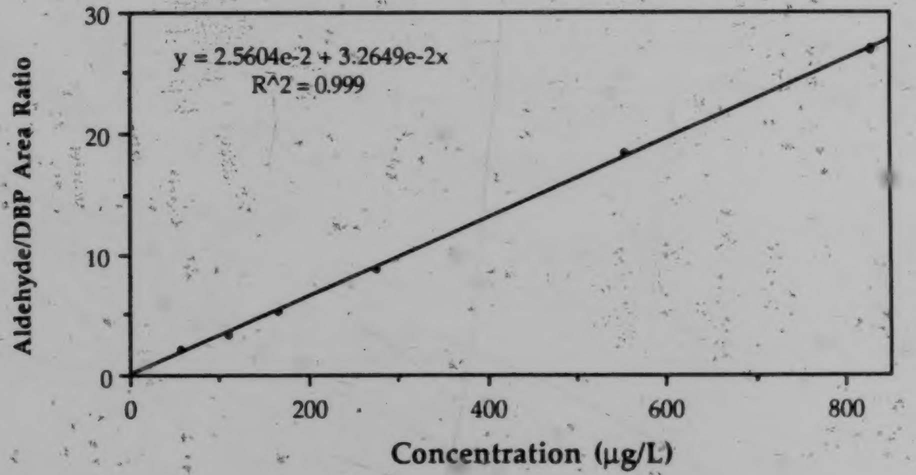


Figure D1.3.10 Hexanal Calibration Curve-July 15, 1990.

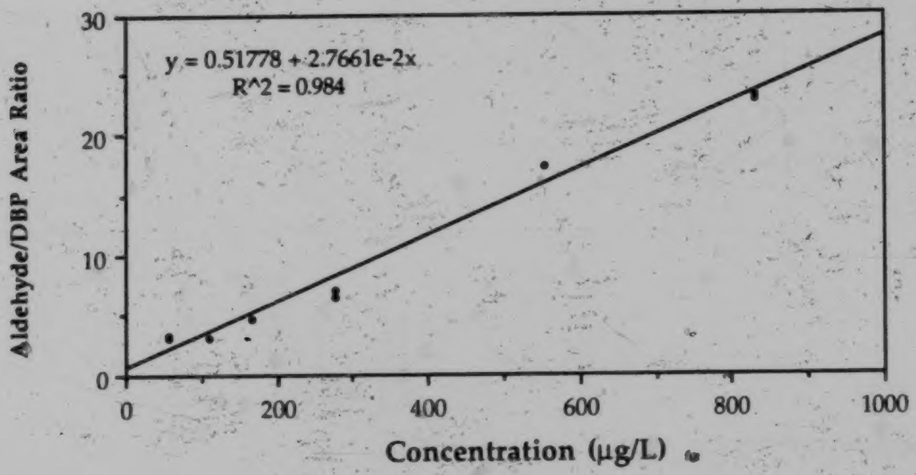


Figure D1.3.11 Heptanal Calibration Curve-July 15, 1990.

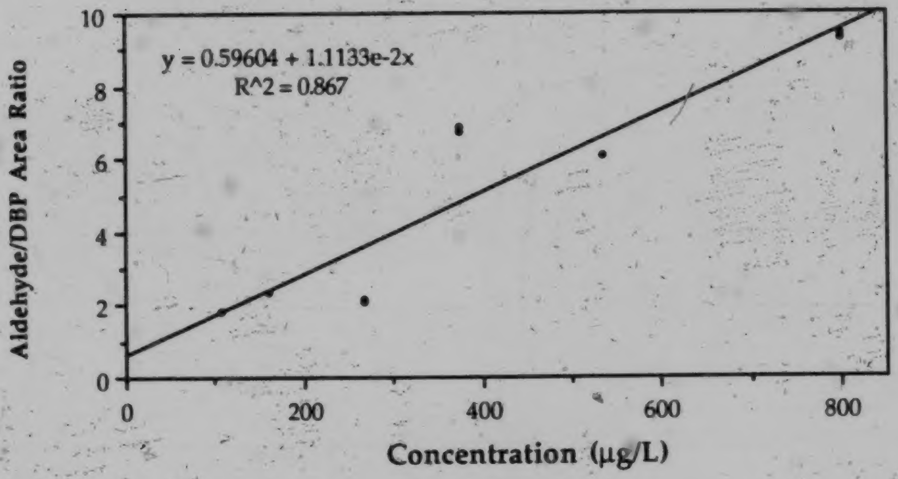


Figure D1.3.12 Octanal Calibration Curve-July 15, 1990.

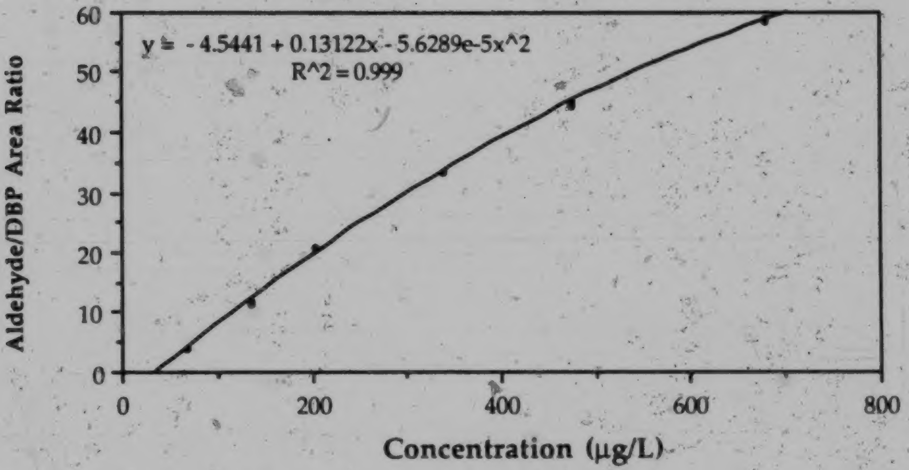


Figure D1.3.13 Benzaldehyde Calibration Curve-July 15, 1990.

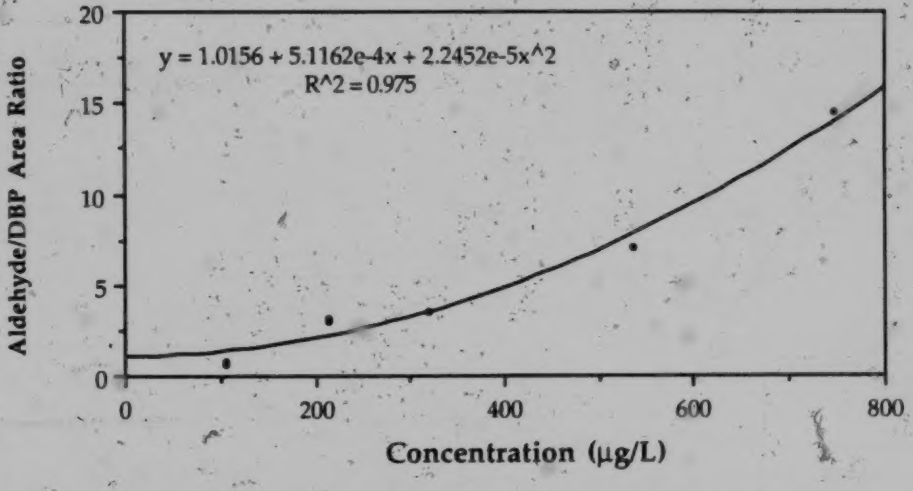


Figure D1.3.14 Phenylacetaldehyde Calibration Curve-July 15, 1990.

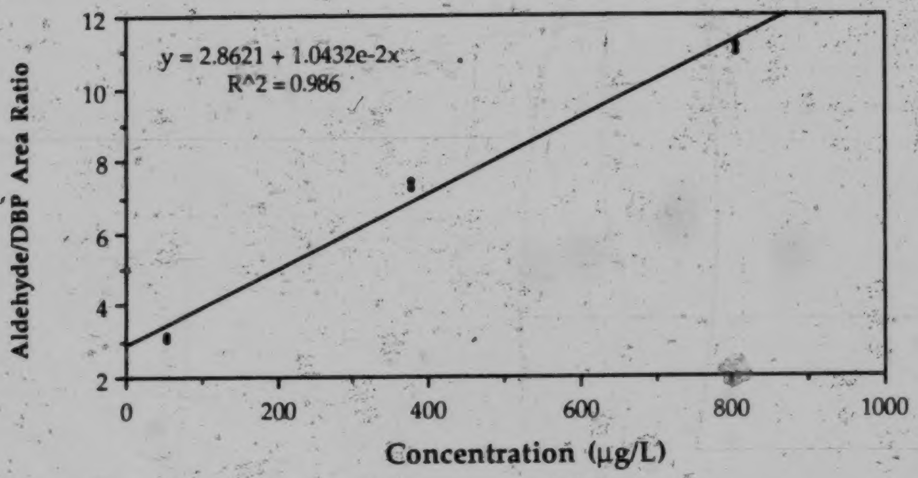


Figure D1.3.15 Nonanal Calibration Curve July 15, 1990.

APPENDIX D1.4

Aldehydes Analysis Results

Table D1.4.1 Aldehydes Analysis for Pool I on July 26, 1990. Studies Comparing Preservation Treatment with Sodium Thiosulfate and Analysis Delay (48 h).

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaler.	Hexanal	Heptanal	Octanal	Benzald.	Θ-acetal.	Nonanal
104	A (S2O3 within 1 h)	110.0	210.4	10.51	16.15			LD		30.01			LD	56.98	82.33	
105	A (S2O3 added IBA)	123.6	209.6	10.11	16.20			LD		31.66			LD	57.00	[illegible].97	
106	B (S2O3 with in 1 h)	96.75	154.1	9.98	15.67			LD					LD	56.44		LD
107	B (S2O3 added IBA)	110.8	149.4		15.42			LD					LD	56.39		LD
108	C (S2O3 within 1 h)	178.3	222.3	10.08	20.66		4.386	LD	22.34				LD	57.88	91.00	
109	C (S2O3 added IBA)	195.5	223.1	9.928	20.99		4.642	LD	29.11				LD	58.14	100.2	
110	D (S2O3 within 1 h)	168.8	222.5	9.946	20.58		4.385	LD	22.84				LD	57.61	92.66	
111	D (S2O3 added IBA)	195.8	222.9	9.735	21.06		4.887	LD	29.89				LD	58.03	96.25	
112	E (S2O3 within 1 h)	1057	637.1	10.26	36.39	16.18	32.68	9.4	108.9		LD	104.3		60.09	131.8	
113	E (S2O3 added IBA)	1077	645.7	9.984	36.82	16.12	34.81	8.0	135.5		LD	83.82		60.69	130.5	
115	A (Delay of 48 h)	97.52	149.4					LD		29.98			LD	56.89		
116	B (Delay of 48 h)	88.78	152.6					LD					LD			LD
117	C (Delay of 48 h)	160.5	222.8		20.04		3.318	LD							98.4	
118	D (Delay of 48 h)	162.3	224.0		20.09		3.694	LD							98.3	
119	E (Delay of 48 h)	1080	656.5	9.969	39.58		31.67	8.7	121.8			97.70	142.0	59.45	126.4	

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.2 Aldehydes Analysis for Pool I on July 30, 1990. Study of Pool Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaler.	Hexanal	Heptanal	Octanal	Benzald.	Ø-acetal.	Nonanal
157	A1	108.3	211.3	12.09	16.99	15.49	1.876	LD	7.130		LD		LD	57.02	81.97	LD
158	A2	111.6	207.6	12.10	16.73	15.45	1.453	LD	6.535		LD		LD	57.16	81.88	LD
159	B1	91.67	159.7		16.23	15.34	0.3664	LD			LD				79.22	LD
160	B2	89.69	153.7		15.59	15.36	0.0000	LD		24.35	LD				78.29	LD
161	B3	87.73	153.0	11.14	15.67	15.37	0.0183	LD		24.41	LD				78.19	LD
163	C1	179.3	226.2	11.32	21.37	15.73	7.009	LD	17.59	25.18	LD	4.858	3.029	58.01	92.68	LD
162	C2	169.7	226.5	11.32	20.94	15.73	6.654	LD	16.62	25.17	LD		1.193	57.96	92.64	LD
164	C3	176.2	224.8	11.72	21.45	15.83	8.021	LD	25.07	25.47	LD	25.04	8.087	58.15	93.68	LD
165	D1	171.7	225.8	10.99	21.00	15.74	6.511	LD	22.99	25.49	LD	3.245	0.8005	58.07	93.59	LD
166	D2	182.6	235.5	12.20	20.91	15.95	6.136	LD	24.23	25.35	LD	17.70	26.26	59.10	108.6	LD
167	D3	176.7	238.2	11.72	21.61	15.86	7.100	LD	29.25	25.63	LD	7.813	6.238	58.15	94.88	LD
168	E1	319.8	351.2	11.34	30.47	15.96	18.26	LD	41.21		1.531	10.51	4.275	58.33	115.4	LD
169	E2	322.8	354.5	11.08	30.87	15.97	19.05	LD	43.66		1.756	25.39	3.632	58.35	115.9	LD
170	E3	318.0	353.1	11.00	31.01	15.98	20.56	LD	36.91	27.01	3.437	26.86	5.041	58.39	125.0	LD

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.3 . Aldehydes Analysis for Pool I on August 1, 1990. Study of Pool Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaler.	Hexanal	Heptanal	Octanal	Benzald.	Φ-acetal.	Nonanal
172	A1	118.9	203.8	10.54	17.20	15.39	2.079	LD	1.009	24.91	LD		LD	57.08	92.65	LD
173	A2	119.3	198.5	10.60	16.80	15.36	1.471	LD	5.916		LD		LD	57.11	84.11	LD
174	A3	116.7	200.3	10.53	17.16	15.36	1.803	LD	10.48		LD		LD	57.03	83.18	LD
175	B1	97.5	149.0		15.97	15.38	0.3586	LD	LD	24.86	LD		LD	56.69	83.08	LD
176	B2	97.79	146.5		15.71	15.26	LD	LD			LD			56.60	79.12	LD
177	B3	100.8	145.6		15.98	15.31	0.1673	LD		24.63	LD			56.60	80.12	LD
178	C1	198.7	220.7		20.85	15.54	5.168	LD	18.59		LD		LD	57.82	94.34	LD
179	C2	204.7	218.8		21.07	15.56	5.362	LD	7.452	25.08	LD	18.37	1.091	57.84	93.31	LD
180	C3	198.4	218.6		20.95	15.55	5.480	LD	8.317	24.98	LD	3.122	0.6592	57.86	95.70	LD
181	D1	189.6	222.1		20.99	15.65	5.762	LD	16.99	24.95	LD	5.395	LD	57.45	91.65	LD
182	D2	198.8	221.3	11.17	20.92	15.68	5.635	LD	17.01	24.96	LD	5.656	4.023	57.79	98.76	LD
183	D3	195.6	221.7	10.96	20.71	15.75	5.782	LD	15.86	24.97	LD	4.238	2.632	57.77	95.67	LD
184	E1	590.6	488.1	11.70	31.66	16.13	21.79	LD	50.96	26.76	LD			62.05	148.4	LD
185	E2	615.5	504.4	11.53	32.97	16.24	28.22	1.040	54.83	26.94	LD	65.89		59.42	121.1	LD
186	E3	642.9	501.2	9.294	32.90	16.32	28.01	1.535	57.52	27.18	0.1742	79.93		60.72	143.6	LD

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.4 Aldehydes Analysis for Pool I on August 6, 1990. Study of Pool Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaler.	Hexanal	Heptanal	Octanal	Benzald.	Θ-acetal.	Nonanal
189	A1	48.85	194.0	9.532	16.66	15.43		LD	6.887	25.12	LD	LD	LD	57.44	91.66	LD
190	A2	37.25	186.3	7.861	16.57	15.41		LD	4.679	25.04	LD	LD	LD	57.55	95.04	
191	A3	51.45	193.9	8.250	16.58	15.42		LD	4.820	25.00	LD	LD	LD	57.43	88.09	LD
192	B1	53.08	146.6	8.007	15.50	15.26		LD	LD	24.42	LD		LD	56.97	84.58	
193	B2	20.13	142.6	8.024	15.35	15.16		LD		24.14	LD		LD	56.66	75.46	
194	B3	14.35	147.2	8.325	16.12	15.23		LD	LD	24.33	LD		LD	56.61	78.83	
195	C1	55.47	218.1	8.450	19.42	15.56		LD	16.21	25.22	LD	63.26		58.28	97.96	LD
196	C2	63.50	218.0	8.321	19.42	15.52		LD	14.99	25.12	LD	77.04		61.38	137.3	LD
197	C3	65.99	219.7	9.619	19.44	15.54		LD	16.40	25.20	LD	76.81		61.43	136.1	LD
198	D1	137.7	234.0	10.24	20.24	15.51		LD	17.16	25.13	LD	55.36		58.40	93.20	LD
199	D2	75.48	230.0	10.15	20.02	15.52		LD	3.529	25.21	LD	75.80		61.29	136.8	LD
200	D3	63.70	219.6	8.416	19.93	15.59		LD	4.557	25.36	LD	78.08		61.47	140.8	
201	E1	612.9	605.9	9.104	33.16	16.38		4.941	78.06	38.27	LD		LD	77.47	177.6	LD
202	E2	363.1	595.4	11.35	31.73	16.35		3.351	73.52	37.29	LD			75.16	124.0	LD
203	E3	612.8	611.3	11.44	33.92	16.53		4.464	87.13	39.87	LD		LD	78.17	188.2	LD

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.5 Aldehydes Analysis for Pool I on October 9, 1990. Study of Pool Profiles Combined with Time Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaleral.	Hexanal	Heptanal	Octanal	Benzald.	ß-acetal.	Nonanal
277	T0A1	2407	348.3	11.18	18.13	16.35	1.746	LD	LD							
278	T0A2	2229	324.5	10.65	17.55	16.11	1.335	LD	LD							
279	T0A3	2293	343.6	10.75	17.88	16.10	1.640	LD	LD							
280	T0B1	187.3	190.0	9.771	16.28	15.80	0.5755	LD							77.07	
281	T0B2	177.6	185.7	9.723	16.06	15.88	0.4029	LD								
282	T0B3	205.4	184.7	9.718	16.08	15.88	0.3892	LD							77.99	
283	T0C1	1200	637.6	10.94	24.73	16.37	7.628	LD	LD							
284	T0C2	1175	621.3	9.371	24.07	16.42	7.300	LD	LD						80.82	
285	T0C3	1061	595.2	10.57	23.27	16.26	6.158	LD	LD						78.46	
286	T0D1	1018	583.2	9.204	23.30	16.17	6.227	LD	LD						79.77	
287	T0D2	1114	613.5	11.12	22.70	16.40	4.831	LD	LD						78.10	
288	T0D3	1039	589.4	11.12	23.12	16.49	4.967	LD	LD						77.82	
289	T0E1	2896	678.8	11.05	32.73	16.41	14.29	LD	3.398		LD				81.28	
290	T0E2	3270	734.8	9.703	34.77	16.66	15.61	LD	0.2168		LD				80.46	
291	T0E3	3219	726.0	9.639	34.23	16.72	15.19	LD	3.847		LD				81.44	

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.5 (Continued) Aldehydes Analysis for Pool I on October 9, 1990. Study of Pool Profiles Combined with Time Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaleral.	Hexanal	Heptanal	Octanal	Benzald.	Φ-acetal.	Nonanal
293	T1A1	2153	499.0	10.91	26.44	16.33	8.861	LD	LD		LD				79.15	
294	T1A2	2063	432.7	10.89	17.44	16.32	1.599	LD	LD	23.62	LD		LD		77.92	
295	T1A3	2222	453.4	11.06	19.12	16.48	3.154	LD	LD	23.91	LD		LD		77.81	LD
296	T1B1	193.7	200.3	10.09	17.03	16.12	1.443	LD	LD		LD		LD		77.69	LD
297	T1B2	189.8	189.6	10.15	16.01	16.17	0.4528	LD	LD	28.14	LD				77.25	LD
298	T1B3	200.2	198.2	8.925	16.84	16.24	1.203	LD	LD	25.41	LD		LD		77.61	
299	T1C1	1183	642.1	11.42	24.25	16.70	7.482	LD	LD	25.41	LD		LD	57.61	78.52	LD
300	T1C2	1127	632.3	11.46	23.84	16.76	7.115	LD	LD	26.44	LD		LD	57.64	78.23	LD
301	T1C3	1110	611.0	10.80	23.81	16.34	7.044	LD	0.3756	24.97	LD			57.72	79.17	LD
302	T1D1	1126	614.4	11.18	23.95	16.53	7.263	LD	1.684		LD			57.75	78.53	LD
303	T1D2	1069	592.5	9.373	23.00	16.48	6.547	LD	4.078	25.36	LD		LD	57.79	79.05	LD
304	T1D3	619.0	504.0	11.00	20.99	16.42	4.575	LD	7.188	25.15	LD		LD	77.39	202.82	77.79
305	T1E1	3450	834.2	9.671	37.11	16.64	18.33	0.6646	93.32	26.70	LD		LD	65.75	86.11	LD
306	T1E2	3202	793.2	12.61	37.00	16.60	18.33	0.4473	99.17	26.68	LD		LD	66.04	86.09	LD
307	T1E3	3356	789.1	9.620	36.97	16.73	18.36	0.5680	99.95	27.51	1.0715		LD	65.99	87.48	LD

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.5 (Continued) Aldehydes Analysis for Pool I on October 9, 1990. Study of Pool Profiles Combined with Time Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaleral.	Hexanal	Heptanal	Octanal	Benzald.	Ø-acetal.	Nonanal
309	T2A1	1898	403.2	10.57	17.34	16.30	1.770	LD			LD		LD	56.89	77.67	LD
310	T2A2	1764	398.5	9.167	17.23	16.39	1.646	LD		25.45	LD	LD	LD	57.28	84.38	LD
311	T2A3	1961	415.1	9.238	17.40	16.41	1.636	LD			LD	LD	0.4821	59.84	114.1	LD
312	T2B1	204.0	183.2	8.791	16.07	16.21	0.5720	LD			LD	LD	LD	56.70	76.90	LD
313	T2B2	172.5	181.7	9.984	16.04	16.17	0.6195	LD	LD	25.05	LD	LD	LD	57.38	90.15	LD
314	T2B3	184.1	193.2	10.1014	17.31	16.23	1.798	LD	LD		LD	LD	LD	57.54	95.91	LD
315	T2C1	1048	618.4	9.565	24.21	16.89	7.690	LD	20.25	25.71	LD			59.83	97.86	LD
316	T2C2	988.7	589.2	9.543	23.11	16.90	6.840	LD	21.68	26.38	LD			58.82	84.03	LD
317	T2C3	1021	588.6	9.386	22.87	16.79	6.759	LD	21.61	26.24	LD			58.81	83.77	LD
318	T2D1	1004	587.1	9.474	23.90	16.76	7.603	LD	22.01	25.74	LD			58.50	82.05	LD
319	T2D2	994.3	582.0	9.466	23.80	16.71	7.636	LD	23.75	25.39	LD			58.59	82.42	LD
320	T2D3	1084	597.1	9.432	29.34	16.74	13.15	LD	32.08	25.56	LD			61.58	124.0	LD
321	T2E1	2830	742.0	11.746	36.03	16.88	18.75	1.327		28.64	0.5662	61.78	81.32	77.44	181.2	10.54
322	T2E2	3042	759.3	11.950	36.53	16.81	19.31	2.143		29.19	1.269	39.21	LD	69.75	90.50	LD
323	T2E3	3121	772.0	11.803	37.08	16.78	19.90	2.612		29.21	2.198	40.56	LD	69.36	90.55	LD

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.6 Aldehydes Analysis for Pool I on November 29, 1990. Study of Pool Profiles Combined with Time Profiles.

Sample ID	Concentration at T0 (µg/L)			Concentration at T1 (µg/L)			Concentration at T2 (µg/L)		
	Formaldehyde	Acetaldehyde	Propional.	Formaldehyde	Acetaldehyde	Propional.	Formaldehyde	Acetaldehyde	Propional.
A1, 2 & 3	2788. ± 8.	453. ± 2.	10.20 ± 0.02	2356. ± 4.	409. ± 2.	10.20 ± 0.03	2375. ± 32.	413. ± 2.	11.00 ± 0.00
B1, 2 & 3	365. ± 6.	225. ± 2.	9.80 ± 0.05	314.0 ± 0.1	207.6 ± 0.5	10.00 ± 0.04	319. ± 1.	204.9 ± 0.5	10.40 ± 0.02
C1, 2 & 3	2441. ± 104.	565. ± 15.	10.60 ± 0.08	2171. ± 34.	516. ± 4.	10.90 ± 0.00	1992. ± 18.	487. ± 3.	10.70 ± 0.00
D1, 2 & 3	2367. ± 59.	549. ± 12.	10.70 ± 0.06	2051. ± 4.	493. ± 1.	10.80 ± 0.27	2261. ± 30.	522. ± 6.	11.50 ± 0.06
E1, 2 & 3	959. ± 5.	652. ± 5.	10.34 ± 0.01	938. ± 2.	622. ± 1.	10.62 ± 0.07	1051. ± 4.	657. ± 6.	11.36 ± 0.03

Table D1.4.7 Aldehydes Analysis for Pool II on July 7, 1990. Studies Comparing Preservation Treatment with Sodium Thiosulfate (on two samples) and Pool Profiles.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaleral.	Hexanal	Heptanal	Octanal	Benzald.	Φ-acetal.	Nonanal
272	α2	95.74	228.7	9.286	18.69	15.28	4.761	LD		24.44	LD		LD	58.48	95.41	
273	β2	154.6	285.6	9.680	19.38	15.38	6.776	LD		24.32	LD	27.89		59.18	101.9	
274	β5	130.7	284.3	9.843	19.48	15.41	7.314	LD	LD		LD	26.56		58.35	91.94	
275	β11	129.3	281.9	9.659	19.19	15.37	6.249	LD			LD	24.92		58.27	91.29	
276	β17	151.2	281.5	8.352	19.43	15.41	7.248	LD	LD		LD	26.65		59.25	102.9	LD
277	χ2	397.4	277.0	10.52	32.61	15.89	18.66	2.934	37.15		LD	34.97		60.45	100.8	
278	δ2	123.8	176.0	9.497	23.50	15.46	9.487	LD	18.27		LD		LD	58.33	105.4	
279	χ2 (IBA)	406.9	265.3	9.989	29.08	15.88	14.39	LD	74.33		-2.301	54.96		64.63	108.1	LD
280	δ2 (IBA)	136.1	177.1	9.444	22.62	15.57	7.080	LD	25.15		LD		LD	58.50	106.6	

Comments: Calibration curve results from July 15, 1990

LD: Less than detection limit

Table D1.4.8 Aldehydes Analysis for Pool II on December, 1990. Study of Pool Profiles Combined with Time Profiles.

Sample Identification	Concentration in µg/L			
	Time 0		Time 1	
	Formaldehyde	Acetaldehyde	Formaldehyde	Acetaldehyde
α1, 2 & 3	322. ± 42.	123. ± 1.	203. ± 2.	156. ± 1.
β1, 2 & 3	84. ± 1.	119.8 ± 0.4	46.8 ± 0.8	121.8 ± 0.6
β4, 5 & 6	63. ± 2.	117.5 ± 0.1	81.5 ± 0.2	122.1 ± 0.3
β7, 8 & 9	62.7 ± 0.7	118.88 ± 0.05	84.5 ± 0.3	122.09 ± 0.04
β10, 11 & 12	72.7 ± 0.1	117.2 ± 0.5	71. ± 1.	120.0 ± 0.4
β13, 14 & 15	75. ± 1.	119. ± 1.	63.0 ± 0.3	123.6 ± 0.6
β16, 17 & 18	45. ± 1.	116.4 ± 0.1	78. ± 1.	125.4 ± 0.8
χ1, 2 & 3	360.0 ± 0.7	127.8 ± 0.3	358. ± 3.	127.9 ± 0.2
δ1, 2 & 3	270. ± 2.	123.3 ± 0.2	315. ± 3.	125.0 ± 0.3

Comments: Calibration curve from July 15, 1990

Table D1.4.9 Aldehydes Analysis for Pool III on July 5, 1990. Studies Comparing Preservation Treatment with Sodium Thiosulfate and Pool Profile.

GC RUN #	Sample ID	Concentration (µg/L)														
		Formald.	Acetald.	Propional.	Isobutanal	Butanal	2-Mebutanal	Isovaleral.	Pentanal	2-Mevaleral.	Hexanal	Heptanal	Octanal	Benzald.	Ø-acetal.	Nonanal
264	X2 (S2O3 added IBA)	164.9	176.0	9.061	16.39	15.48	1.084	LD	5.232		LD			57.02	80.64	LD
265	Y2 (S2O3 added IBA)	152.9	170.8	8.936	16.00	15.44	0.6966	LD	LD		LD			56.89	79.22	
266	Z(3:4) (S2O3 added IBA)	147.8	173.3	8.718	16.93	15.53	0.9797	LD	5.542		LD			56.86	79.52	
267	Z(1:5) (S2O3 added IBA)	147.1	172.0	8.893	16.10	15.46	0.6930	LD	6.432		LD			56.90	78.97	
268	X2 (S2O3 within 1 h)	143.3	172.4	9.178	16.23	15.56	1.015	LD	7.979		LD		LD	56.88	79.85	LD
269	Y2 (S2O3 within 1 h)	157.7	169.4	9.319	16.13	15.61	0.8061	LD	6.608		LD		LD	56.89	80.23	LD
270	Z(3:4) (S2O3 within 1 h)	158.4	170.5	9.197	16.29	15.58	0.9614	LD	8.108		LD		LD	56.98	81.82	LD
271	Z(1:5) (S2O3 within 1 h)	175.1	175.2	9.253	16.28	15.65	0.9603	LD	9.550		LD		LD	57.06	82.15	LD

Comments: Calibration curve results from July 15, 1990
LD: Less than detection limit

Table D1.4.10 Aldehydes Analysis for Pool III on December 5, 1990. Study of Pool Profile Combined with Time Profile.

Sample Identification	Average Concentration in µg/L					
	Time 0		Time 1		Time 2	
	Formaldehyde	Acetaldehyde	Formaldehyde	Acetaldehyde	Formaldehyde	Acetaldehyde
X1, 2, 3, 4 & 5	615. ± 50.		410. ± 16.		403. ± 4.	
Y1, 2, 3, 4 & 5	454. ± 26.		407. ± 5.		349. ± 1.	115.59 ± 0.02
Z1, 2, 3, 4 & 5	429. ± 12.		373. ± 14.		367.9 ± 0.3	

APPENDIX D2

Chlorine Speciation

APPENDIX D2.1

Standardization of FAS for DPD Method

APPENDIX D2.1 Standardization of FAS for DPD Method

Normally ferrous ammonium sulfate (FAS) is standardized using Method 4500-Cl F of Standard Methods for the Examination of Water and Wastewater. This method requires the use of barium diphenylamine sulfonate as indicator, this latter chemical was not available and seemed difficult to obtained in any chemical catalogue. Since it was not readily available, FAS had to be standardized against a known volume of a standardized chlorine solution. Standardization of the FAS titrant was performed by combining Method 4500-Cl B. sections 2, 3 and 4 and, Method 4500-Cl C., section 3. The following detailed procedures were combined to obtain the standardized chlorine solution.

In order to standardize a chlorine solution, one must used a reducing solution (sodium thiosulfate), which was standardized against a primary solution of an oxidant agent (potassium dichromate).

The oxidant solution in our experiment was the primary standard potassium dichromate ($K_2Cr_2O_7$) at a concentration of 0.1000 N. This solution was used to standardized a 0.1 N sodium thiosulfate solution ($Na_2S_2O_3$), which is diluted to 0.01 N $Na_2S_2O_3$. This 0.01 N $Na_2S_2O_3$ solution was used to standardized the chlorine solution prepared from sodium hypochlorite (NaOCl), which was used to standardized the FAS solutions used in the DPD method.

To standardization the chlorine solution, two steps are required. In the first step, the titration of the chlorine solution is performed with 0.01 N $Na_2S_2O_3$. The second step is the titration of the water used to prepare the chlorine solution (Blank titration). When performing the blank titration, two situation can occur: 1) a blue colour develops upon addition of the starch indicator to the blank sample or 2) no blue colour develops upon addition of the starch indicator to the blank sample. If case No. 1 develops, a simple titration applies and the blank correction is negative. If No. 2 develops, than a back titration with a pre-standardized solution of 0.0282 N iodine is uses to make the blue coloration appear and than 0.01 N $Na_2S_2O_3$ is used to titrate the blue tint out. The difference between the two readings is added as a positive correction to the titration of the chlorine solution. The equation that applies is given by:

$$\text{Equation D2.1} \qquad \text{mg Cl as } Cl_2/L = \frac{(A + B) \times N \times 35450}{\text{mL sample}}$$

where: A = mL of titrant added for the chlorine sample,
B = correction from the back titration of blank,
N = Normality of $Na_2S_2O_3$ diluted solution.

-Primary Standard: Potassium Dichromate

$K_2Cr_2O_7$: F.W.: 294.19 g/mole
eq.wt.: 40.03 g/eq
weight: 4.9126 g

Normality: 0.1002 N

$$6\acute{e} + 14\,H^+ + Cr_2O_7^{2-} \rightarrow 2\,Cr^{3+} + 7\,H_2O$$

-Sodium Thiosulfate 0.1 N

$Na_2S_2O_3$: F.W.: 248.18 g/mole (penta hydrated form)
eq.wt.: 124.09 g/eq

$$S_2O_3^{2-} + H_2O \rightarrow S_2O_4^{2-} + 2\,H^+ + 2\acute{e}$$

Standardization procedure follows method 4500-Cl B. Normality of the solution is given by:

$$No \times Vo = Nr \times Vr$$

$$Nr = \frac{No \times Vo}{Vr}$$

where:
No = Normality of the oxidant, 0.1002 N $K_2Cr_2O_7$
Vo = Volume of oxidant use for the titration, 10.00 mL
Vr = Volume of reducing agent use (titrant added)

Table D2.1 Standardization of 0.1 N $Na_2S_2O_3$ with 0.1002 N $K_2Cr_2O_7$.

Volume of Titrant	**$Na_2S_2O_3$ Normality**
mL	**N**
10.02	0.1000
10.09	0.0993
10.04	0.0998

Average Normality	**Standard Deviation**
N	**N**
0.0997	0.0004

-Sodium Thiosulfate 0.01N:

10 fold dilution: 0.00997 ± 0.00004 N

-Chlorine Solution Standardization:

0.1 N Iodine (Standardized with 0.0997 N $Na_2S_2O_3$) following method 4500-Cl B.

$$I_2 \quad + \quad 2e \quad \rightarrow \quad 2\,I^-$$

$$No \times Vo = Nr \times Vr$$

$$No = \frac{Nr \times Vr}{Vo}$$

where:
Nr = Normality of reducing agent, 0.0997 N $Na_2S_2O_3$
Vr = Volume of reducing agent (titrant added)
Vo = Volume of oxidant use for the titration, 10.00 mL

Table D2.2 Standardization of 0.1 N Iodine with 0.0997 N $Na_2S_2O_3$.

Volume of Titrant mL	0.1 N Iodine Normality N
10.17	0.1014
10.15	0.1012
10.13	0.1010

Average Normality N	Standard Deviation N
0.1012	0.0002

0.0282 N Iodine (Standardized with 0.0997 N $Na_2S_2O_3$), 25.00 mL were used following method 4500-Cl B.

$$No \times Vo = Nr \times Vr$$

$$No = \frac{Nr \times Vr}{Vo}$$

where:
Nr = Normality of reducing agent, 0.0997 N $Na_2S_2O_3$
Vr = Volume of reducing agent (titrant added)
Vo = Volume of oxidant use for the titration, 25.00 mL

Table D2.3 Standardization of 0.0282 N Iodine with 0.0997 N $Na_2S_2O_3$.

Volume of Titrant	0.0282 N Iodine Normality
mL	N
7.47	0.02979
7.44	0.02967
7.44	0.02967

Average Normality	Standard Deviation
N	N
0.02971	0.00007

Chlorine solution and Blank titration, calculation following equation D2.1

Table D2.4 Chlorine Standardization with Blank Correction Included.

Chlorine	**Blank**		
Volume of Titrant	**Volume of 0.0100 N $Na_2S_2O_3$**	**Volume of 0.0282 N Iodine**	**Positive Correction**
mL	**mL**	**mL**	**mL**
9.06	0.28	0.07	0.21
9.29	0.31	0.17	0.14
9.15	0.31	0.13	0.18

Average Volume (Chlorine)	**Average Positive Correction**	**Average Concentration**	**Average Concentration**
mL	**mL**	**mg of Cl as Cl_2/L**	**mN**
9.17	0.18	6.6093	0.1864

-FAS Standardization

Standardization of FAS is performed following method 4500-Cl B, section 3.

$$2\,Fe^{2+} \rightarrow 2\,Fe^{3+} + 2é$$

$$2é + 2\,OCl^{-} + 4\,H^{+} \rightarrow Cl_2 + 2\,H_2O$$

$$No \times Vo = Nr \times Vr$$

$$Nr = \frac{No \times Vo}{Vr}$$

where: No = Normality of oxidant, 0.1864 mN NaOCl
Vo = Volume of oxidant, use 100.00 mL
Vr = Volume of reducing agent (titrant), FAS

Table D2.5 Standardization of FAS from August 2, 1990.

Volume of Titrant mL	Concentration of FAS N	Concentration of FAS mg of Cl as Cl2/L
6.43	0.0028995	102.79
6.41	0.0029086	103.11
6.44	0.0028950	102.63

Average Concentration N	Average Concentration mg of Cl as Cl2/L
0.002901 ± 0.000007	102.84 ± 0.24

Table D2.6 Standardization of FAS from October 4, 1990.

Volume of Titrant	Concentration of FAS	Concentration of FAS
mL	N	mg of Cl as Cl2/L
6.55	0.0028464	100.90
6.53	0.0028551	101.21
6.57	0.0028377	100.60

Average Concentration	Average Concentration
N	mg of Cl as Cl2/L
0.002846 ± 0.000009	100.90 ± 0.31

Table D2.7 Standardization of FAS from December 6, 1990.

Volume of Titrant	Concentration of FAS	Concentration of FAS
mL	N	mg of Cl as Cl2/L
6.48	0.0028771	101.99
6.52	0.0028595	101.37
6.46	0.0028861	102.31

Average Concentration	Average Concentration
N	mg of Cl as Cl2/L
0.00287 ± 0.00001	101.89± 0.48

Table D2.8 Standardization of FAS from December 13, 1990.

Volume of Titrant	Concentration of FAS	Concentration of FAS
mL	N	mg of Cl as Cl2/L
6.32	0.0029500	104.58
6.35	0.0029360	104.08
6.31	0.0029547	104.74

Average Concentration	Average Concentration
N	mg of Cl as Cl2/L
0.00295 ± 0.00001	104.47 ± 0.34

APPENDIX D2.2

Chlorine Speciation Results

Table D2.2.1 Summary of Chlorine Speciation Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L			
		July 26 1990	July 30 1990	August 1 1990	August 6 1990
A1	Free Chlorine		1.95 ± 0.05	1.57 ± 0.09	2.03 ± 0.04
	Mono-Chloramine		0.15 ± 0.02	0.16 ± 0.05	0.15 ± 0.11
	Di-chloramine		0.20 ± 0.17	0.25 ± 0.00	0.31 ± 0.11
	Nitrogen Trichloride		1.28 ± 0.12	1.10 ± 0.07	0.92 ± 0.04
	Combined Chlorine		1.63 ± 0.21	1.51 ± 0.09	1.38 ± 0.16
	Total Residual		3.58 ± 0.21	3.08 ± 0.12	3.41 ± 0.17
A2	Free Chlorine	2.15 ± 0.08	2.13 ± 0.16	1.86 ± 0.06	2.15 ± 0.02
	Mono-Chloramine	0.21 ± 0.05	0.16 ± 0.04	0.10 ± 0.09	0.11 ± 0.05
	Di-chloramine	0.57 ± 0.16	0.21 ± 0.23	0.19 ± 0.13	0.35 ± 0.06
	Nitrogen Trichloride	0.77 ± 0.06	1.09 ± 0.15	1.18 ± 0.24	0.90 ± 0.06
	Combined Chlorine	1.55 ± 0.18	1.46 ± 0.28	1.47 ± 0.29	1.36 ± 0.10
	Total Residual	3.70 ± 0.20	3.59 ± 0.32	3.33 ± 0.29	3.51 ± 0.10
A3	Free Chlorine		2.23 ± 0.06	1.86 ± 0.09	2.17 ± 0.11
	Mono-Chloramine		0.33 ± 0.08	0.09 ± 0.09	0.10 ± 0.15
	Di-chloramine		0.57 ± 0.07	0.39 ± 0.02	0.43 ± 0.07
	Nitrogen Trichloride		0.92 ± 0.01	0.73 ± 0.24	0.59 ± 0.19
	Combined Chlorine		1.82 ± 0.11	1.21 ± 0.26	1.12 ± 0.25
	Total Residual		4.05 ± 0.12	3.07 ± 0.27	3.29 ± 0.27
B1	Free Chlorine		2.81 ± 0.04	2.34 ± 0.02	1.94 ± 0.09
	Mono-Chloramine		0.00 ± 0.00	0.05 ± 0.04	0.00 ± 0.00
	Di-chloramine		0.14 ± 0.12	0.37 ± 0.14	0.40 ± 0.03
	Nitrogen Trichloride		0.47 ± 0.09	0.41 ± 0.03	0.09 ± 0.22
	Combined Chlorine		0.61 ± 0.15	0.83 ± 0.15	0.49 ± 0.22
	Total Residual		3.42 ± 0.16	3.17 ± 0.15	2.43 ± 0.24
B2	Free Chlorine	1.93 ± 0.49	2.92 ± 0.03	2.33 ± 0.01	1.89 ± 0.04
	Mono-Chloramine	0.00 ± 0.00	0.11 ± 0.12	0.12 ± 0.04	0.00 ± 0.00
	Di-chloramine	0.01 ± 0.98	0.30 ± 0.00	0.31 ± 0.10	0.21 ± 0.01
	Nitrogen Trichloride	1.59 ± 0.91	0.50 ± 0.07	0.35 ± 0.11	0.51 ± 0.17
	Combined Chlorine	1.60 ± 1.34	0.91 ± 0.14	0.78 ± 0.15	0.72 ± 0.17
	Total Residual	3.53 ± 1.42	3.83 ± 0.14	3.11 ± 0.15	2.61 ± 0.17
B3	Free Chlorine		3.03 ± 0.20	2.41 ± 0.05	1.92 ± 0.02
	Mono-Chloramine		0.05 ± 0.07	0.00 ± 0.00	0.00 ± 0.00
	Di-chloramine		0.25 ± NA	0.26 ± 0.06	0.24 ± 0.09
	Nitrogen Trichloride		0.04 ± NA	0.48 ± 0.01	0.29 ± 0.00
	Combined Chlorine		0.34 ± NA	0.74 ± 0.06	0.53 ± 0.09
	Total Residual		3.37 ± NA	3.15 ± 0.08	2.45 ± 0.09

Table D2.2.1 (Continued) Summary of Chlorine Speciation Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L			
		July 26 1990	July 30 1990	August 1 1990	August 6 1990
C1	Free Chlorine		0.87 ± 0.06	1.47 ± 0.19	1.49 ± 0.05
	Mono-Chloramine		0.32 ± 0.04	0.23 ± 0.20	0.35 ± 0.04
	Di-chloramine		0.00 ± 0.09	0.33 ± 0.43	0.53 ± 0.13
	Nitrogen Trichloride		3.42 ± 0.10	2.14 ± 0.63	2.14 ± 0.23
	Combined Chlorine		3.74 ± 0.14	2.70 ± 0.79	3.02 ± 0.27
	Total Residual		4.51 ± 0.15	4.17 ± 0.81	4.51 ± 0.27
C2	Free Chlorine	1.97 ± 0.14	1.12 ± 0.11	1.46 ± 0.08	1.54 ± 0.12
	Mono-Chloramine	0.42 ± 0.11	0.20 ± 0.08	0.31 ± 0.05	0.26 ± 0.03
	Di-chloramine	0.67 ± 0.24	0.97 ± 0.56	0.94 ± 0.53	0.44 ± 0.13
	Nitrogen Trichloride	2.03 ± 0.62	1.58 ± 0.08	1.19 ± 0.60	2.06 ± 0.44
	Combined Chlorine	3.12 ± 0.67	2.75 ± 0.57	2.44 ± 0.80	2.76 ± 0.46
	Total Residual	5.09 ± 0.69	3.87 ± 0.58	3.90 ± 0.81	4.30 ± 0.48
C3	Free Chlorine		0.98 ± 0.06	1.39 ± 0.08	1.60 ± 0.06
	Mono-Chloramine		0.25 ± 0.11	0.33 ± 0.07	0.33 ± 0.07
	Di-chloramine		0.66 ± 0.05	0.81 ± 0.09	0.53 ± 0.09
	Nitrogen Trichloride		1.69 ± 0.26	1.08 ± 0.10	2.05 ± 0.33
	Combined Chlorine		2.60 ± 0.29	2.22 ± 0.15	2.91 ± 0.35
	Total Residual		3.58 ± 0.29	3.61 ± 0.17	4.51 ± 0.35
D1	Free Chlorine		0.74 ± 0.05	1.10 ± 0.05	1.34 ± 0.01
	Mono-Chloramine		0.39 ± 0.04	0.33 ± 0.06	0.34 ± 0.06
	Di-chloramine		0.52 ± NA	0.44 ± 0.16	0.62 ± 0.17
	Nitrogen Trichloride		1.97 ± 0.64	1.61 ± 0.30	1.98 ± 0.36
	Combined Chlorine		2.88 ± NA	2.38 ± 0.35	2.94 ± 0.40
	Total Residual		3.62 ± NA	3.48 ± 0.35	4.28 ± 0.40
D2	Free Chlorine	1.80 ± 0.17	0.99 ± 0.12	1.24 ± 0.03	1.43 ± 0.18
	Mono-Chloramine	0.29 ± 0.26	0.52 ± 0.16	0.35 ± 0.06	0.27 ± 0.15
	Di-chloramine	0.55 ± 0.03	0.69 ± 0.27	0.60 ± 0.04	0.51 ± 0.41
	Nitrogen Trichloride	2.27 ± 0.13	1.72 ± 0.74	1.93 ± 0.14	1.94 ± 1.06
	Combined Chlorine	3.11 ± 0.29	2.93 ± 0.80	2.88 ± 0.16	2.72 ± 1.15
	Total Residual	4.91 ± 0.34	3.92 ± 0.81	4.12 ± 0.16	4.15 ± 1.16
D3	Free Chlorine		0.80 ± 0.18	1.30 ± 0.08	2.05 ± 0.55
	Mono-Chloramine		0.32 ± 0.13	0.25 ± 0.06	0.34 ± 0.14
	Di-chloramine		0.37 ± 0.01	0.58 ± 0.01	0.71 ± 0.19
	Nitrogen Trichloride		2.49 ± 0.12	1.59 ± 0.13	0.76 ± 0.84
	Combined Chlorine		3.18 ± 0.18	2.42 ± 0.14	1.81 ± 0.87
	Total Residual		3.98 ± 0.25	3.72 ± 0.16	3.86 ± 1.03

Table D2.2.1 (Continued) Summary of Chlorine Speciation Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L			
		July 26 1990	July 30 1990	August 1 1990	August 6 1990
E1	Free Chlorine		0.95 ± 0.19	0.80 ± 0.06	0.99 ± 0.05
	Mono-Chloramine		0.28 ± 0.06	0.34 ± 0.04	0.54 ± 0.03
	Di-chloramine		0.51 ± 0.12	0.88 ± 0.38	1.33 ± 0.27
	Nitrogen Trichloride		1.89 ± 0.32	2.83 ± 0.73	5.03 ± 0.19
	Combined Chlorine		2.68 ± 0.35	4.05 ± 0.82	6.90 ± 0.33
	Total Residual		3.63 ± 0.40	4.85 ± 0.83	7.89 ± 0.34
E2	Free Chlorine	0.93 ± 0.05	1.24 ± 0.26	0.89 ± 0.04	0.47 ± 0.08
	Mono-Chloramine	0.76 ± 0.06	0.15 ± 0.14	0.36 ± 0.38	0.45 ± 0.06
	Di-chloramine	1.42 ± 0.09	0.88 ± 0.39	0.94 ± 0.21	2.17 ± 0.13
	Nitrogen Trichloride	6.49 ± 0.99	1.13 ± 0.81	2.32 ± 0.60	3.90 ± 0.33
	Combined Chlorine	8.67 ± 1.00	2.16 ± 0.91	3.62 ± 0.74	6.52 ± 0.36
	Total Residual	9.60 ± 1.00	3.40 ± 0.95	4.51 ± 0.74	6.99 ± 0.37
E3	Free Chlorine		0.75 ± 0.24	0.83 ± 0.03	0.41 ± 0.06
	Mono-Chloramine		0.25 ± 0.05	0.38 ± 0.07	0.44 ± 0.03
	Di-chloramine		0.57 ± 0.06	0.66 ± 0.14	2.12 ± 0.12
	Nitrogen Trichloride		1.55 ± 0.07	2.90 ± 0.06	3.60 ± 0.00
	Combined Chlorine		2.37 ± 0.10	3.94 ± 0.17	6.16 ± 0.12
	Total Residual		3.12 ± 0.26	4.77 ± 0.17	6.57 ± 0.14

Table D2.2.2 Summary of Chlorine Speciation Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L					
		October 9 1990			November 29 1990		
		T0	T1	T2	T0	T1	T2
A1	Free Chlorine	1.28 ± 0.05	1.09 ± 0.32	1.15 ± 0.08	2.27 ± 0.22	1.82 ± 0.10	1.78 ± 0.06
	Mono-Chloramine	0.20 ± 0.09	0.17 ± 0.15	0.14 ± 0.05	0.30 ± 0.11	0.15 ± 0.13	0.16 ± 0.05
	Di-chloramine	0.19 ± 0.08	0.35 ± NA	0.17 ± 0.02	0.03 ± 0.25	0.04 ± 0.19	0.02 ± 0.11
	Nitrogen Trichloride	1.12 ± 0.19	1.23 ± NA	0.95 ± 0.26	2.40 ± 0.80	1.64 ± 0.50	1.76 ± 0.11
	Combined Chlorine	1.51 ± 0.22	1.75 ± NA	1.26 ± 0.27	2.73 ± 0.85	1.83 ± 0.55	1.94 ± 0.16
	Total Residual	2.79 ± 0.23	2.84 ± NA	2.41 ± 0.28	5.00 ± 0.87	3.65 ± 0.56	3.72 ± 0.17
A2	Free Chlorine	1.23 ± 0.06	1.20 ± 0.05	1.11 ± 0.10	2.45 ± 0.17	1.99 ± 0.20	1.79 ± 0.05
	Mono-Chloramine	0.23 ± 0.05	0.22 ± 0.07	0.18 ± 0.04	0.10 ± 0.05	0.13 ± 0.11	0.17 ± 0.05
	Di-chloramine	0.07 ± 0.11	0.00 ± 0.02	0.13 ± 0.14	0.18 ± 0.24	0.01 ± 0.01	0.03 ± 0.07
	Nitrogen Trichloride	1.30 ± 0.10	1.31 ± 0.00	1.41 ± 0.09	1.52 ± 0.24	1.63 ± 0.31	1.78 ± 0.09
	Combined Chlorine	1.60 ± 0.16	1.53 ± 0.07	1.72 ± 0.17	1.80 ± 0.34	1.77 ± 0.33	1.98 ± 0.12
	Total Residual	2.83 ± 0.17	2.73 ± 0.09	2.83 ± 0.20	4.25 ± 0.38	3.76 ± 0.39	3.77 ± 0.13
A3	Free Chlorine	1.40 ± 0.10	0.97 ± 0.04	1.17 ± 0.07	2.19 ± 0.05	1.65 ± 0.03	1.62 ± 0.08
	Mono-Chloramine	0.07 ± 0.06	0.14 ± 0.03	0.19 ± 0.09	0.19 ± 0.04	0.23 ± 0.04	0.17 ± 0.01
	Di-chloramine	0.21 ± 0.05	0.04 ± 0.04	0.00 ± 0.08	0.15 ± 0.11	0.00 ± 0.03	0.00 ± 0.09
	Nitrogen Trichloride	0.98 ± 0.16	1.14 ± 0.07	1.56 ± 0.16	1.69 ± 0.10	1.97 ± 0.10	1.88 ± 0.37
	Combined Chlorine	1.26 ± 0.18	1.32 ± 0.09	1.75 ± 0.20	2.03 ± 0.15	2.20 ± 0.11	2.05 ± 0.38
	Total Residual	2.66 ± 0.20	2.29 ± 0.09	2.92 ± 0.21	4.22 ± 0.16	3.85 ± 0.12	3.67 ± 0.39

Table D2.2.2 (Continued) Summary of Chlorine Speciation Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L					
		October 9 1990			November 29 1990		
		T0	T1	T2	T0	T1	T2
B1	Free Chlorine	2.31 ± 0.09	2.22 ± 0.06	2.27 ± 0.05	2.23 ± 0.09	2.10 ± 0.02	1.91 ± 0.07
	Mono-Chloramine	0.04 ± 0.06	0.00 ± 0.00	0.02 ± 0.03	0.00 ± 0.00	0.04 ±0.08	0.05 ± 0.09
	Di-chloramine	0.11 ± 0.08	0.16 ± 0.01	0.15 ± 0.13	0.09 ± 0.06	0.08 ± 0.08	0.06 ± 0.25
	Nitrogen Trichloride	0.46 ± 0.06	0.33 ± 0.01	0.38 ± 0.06	0.70 ± 0.04	0.71 ± 0.09	0.78 ± 0.04
	Combined Chlorine	0.61 ± 0.12	0.49 ± 0.01	0.55 ± 0.15	0.79 ± 0.07	0.83 ± 0.14	0.89 ± 0.27
	Total Residual	2.92 ± 0.15	2.71 ± 0.06	2.82 ± 0.15	3.02 ± 0.12	2.93 ± 0.15	2.80 ± 0.28
B2	Free Chlorine	2.68 ± 0.34	2.41 ± 0.03	2.51 ± 0.02	2.40 ± 0.02	2.08 ± 0.04	2.01 ± 0.04
	Mono-Chloramine	0.08 ± 0.11	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.07
	Di-chloramine	0.01 ± 0.16	0.11 ± 0.06	0.10 ± 0.04	0.28 ± 0.36	0.03 ± 0.16	0.00 ± 0.08
	Nitrogen Trichloride	0.69 ± 0.43	0.32 ± 0.03	0.33 ± 0.04	0.22 ± 0.77	0.79 ± 0.37	0.95 ± 0.17
	Combined Chlorine	0.78 ± 0.47	0.43 ± 0.07	0.43 ± 0.06	0.50 ± 0.85	0.82 ± 0.40	1.03 ± 0.20
	Total Residual	3.46 ± 0.58	2.84 ± 0.07	2.94 ± 0.06	2.90 ± 0.85	2.90 ± 0.41	3.04 ± 0.20
B3	Free Chlorine	2.59 ± 0.14	2.25 ± 0.04	2.25 ± 0.03	2.21 ± 0.07	2.00 ± 0.03	1.89 ± 0.06
	Mono-Chloramine	0.03 ± 0.06	0.00 ± 0.00	0.00 ± 0.00	0.09 ± 0.08	0.00 ± 0.00	0.05 ± 0.09
	Di-chloramine	0.19 ± 0.16	0.05 ± 0.04	0.01 ± 0.27	0.00 ± 0.02	0.05 ± 0.18	0.00 ± 0.11
	Nitrogen Trichloride	0.27 ± 0.30	0.33 ± 0.13	0.54 ± 0.37	1.00 ± 0.50	0.83 ± 0.20	0.92 ± 0.19
	Combined Chlorine	0.49 ± 0.35	0.38 ± 0.14	0.55 ± 0.46	1.09 ± 0.51	0.88 ± 0.27	0.97 ± 0.24
	Total Residual	3.08 ± 0.37	2.63 ± 0.14	2.80 ± 0.46	3.30 ± 0.51	2.88 ± 0.27	2.86 ± 0.24

Table D2.2.2 (Continued) Summary of Chlorine Speciation Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L					
		October 9 1990			November 29 1990		
		T0	T1	T2	T0	T1	T2
C1	Free Chlorine	0.25 ± 0.07	0.49 ± 0.01	0.99 ± 0.03	1.79 ± 0.14	1.20 ± 0.03	1.19 ± 0.09
	Mono-Chloramine	0.08 ± 0.07	0.17 ± 0.03	0.15 ± 0.06	0.28 ± 0.06	0.30 ± 0.09	0.28 ± 0.10
	Di-chloramine	0.22 ± 0.16	0.03 ± 0.04	0.04 ± 0.11	0.01 ± 0.22	0.11 ± 0.01	0.07 ± 0.06
	Nitrogen Trichloride	1.38 ± 0.21	1.78 ± 0.06	1.83 ± 0.01	4.68 ± 0.63	4.22 ± 0.06	3.88 ± 0.07
	Combined Chlorine	1.68 ± 0.27	1.98 ± 0.08	2.02 ± 0.13	4.97 ± 0.67	4.63 ± 0.11	4.23 ± 0.14
	Total Residual	1.93 ± 0.28	2.47 ± 0.08	3.01 ± 0.13	6.76 ± 0.68	5.83 ± 0.11	5.42 ± 0.16
C2	Free Chlorine	0.27 ± 0.08	0.55 ± 0.06	1.07 ± 0.06	1.95 ± 0.03	0.86 ± 0.02	1.08 ± 0.06
	Mono-Chloramine	0.21 ± 0.10	0.20 ± 0.03	0.22 ± 0.03	0.34 ± 0.09	0.29 ± 0.08	0.31 ± 0.16
	Di-chloramine	0.09 ± 0.09	0.06 ± 0.08	0.06 ± 0.01	0.10 ± 0.06	0.07 ± 0.00	0.03 ± 0.16
	Nitrogen Trichloride	1.49 ± 0.11	1.70 ± 0.17	1.85 ± 0.04	4.34 ± 0.06	4.46 ± 0.11	3.93 ± 0.39
	Combined Chlorine	1.79 ± 0.17	1.96 ± 0.19	2.13 ± 0.05	4.78 ± 0.12	4.82 ± 0.14	4.27 ± 0.45
	Total Residual	2.06 ± 0.19	2.51 ± 0.20	3.20 ± 0.08	6.73 ± 0.13	5.68 ± 0.14	5.35 ± 0.45
C3	Free Chlorine	0.27 ± 0.01	0.50 ± 0.09	0.75 ± 0.50	1.83 ± 0.06	1.06 ± 0.05	0.43 ± 1.13
	Mono-Chloramine	0.14 ± 0.01	0.22 ± 0.01	0.44 ± 0.50	0.37 ± 0.04	0.33 ± 0.06	1.03 ± 1.16
	Di-chloramine	0.35 ± 0.01	0.09 ± 0.11	0.09 ± 0.07	0.00 ± 0.10	0.19 ± 0.11	0.09 ± 0.36
	Nitrogen Trichloride	1.15 ± 0.09	1.85 ± 0.13	1.72 ± 0.03	4.83 ± 0.01	4.10 ± 0.24	3.87 ± 0.60
	Combined Chlorine	1.64 ± 0.09	2.16 ± 0.17	2.25 ± 0.51	5.20 ± 0.11	4.62 ± 0.27	4.99 ± 1.35
	Total Residual	1.91 ± 0.09	2.66 ± 0.19	3.00 ± 0.71	7.03 ± 0.12	5.68 ± 0.28	5.42 ± 1.76

Table D2.2.2 (Continued) Summary of Chlorine Speciation Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L					
		October 9 1990			November 29 1990		
		T0	T1	T2	T0	T1	T2
D1	Free Chlorine	0.21 ± 0.02	0.50 ± 0.03	0.83 ± 0.07	1.63 ± 0.10	1.19 ± 0.02	1.03 ± 0.07
	Mono-Chloramine	0.17 ± 0.03	0.54 ± 0.64	0.15 ± 0.07	0.27 ± 0.06	0.22 ± 0.02	0.31 ± 0.08
	Di-chloramine	0.11 ± 0.07	0.16 ± NA	0.24 ± 0.23	0.38 ± 0.11	0.09 ± 0.02	0.00 ± 0.08
	Nitrogen Trichloride	1.49 ± 0.09	1.49 ± NA	1.49 ± 0.31	3.95 ± 0.10	4.04 ± 0.11	3.97 ± 0.30
	Combined Chlorine	1.77 ± 0.12	2.19 ± NA	1.88 ± 0.39	4.60 ± 0.16	4.35 ± 0.11	4.28 ± 0.32
	Total Residual	1.98 ± 0.12	2.69 ± NA	2.71 ± 0.40	6.23 ± 0.19	5.54 ± 0.12	5.31 ± 0.33
D2	Free Chlorine	0.23 ± 0.04	0.56 ± 0.03	0.91 ± 0.04	1.20 ± 0.07	0.97 ± 0.09	1.25 ± 0.24
	Mono-Chloramine	0.23 ± 0.05	0.21 ± 0.06	0.16 ± 0.12	0.31 ± 0.17	0.15 ± 0.13	0.28 ± 0.15
	Di-chloramine	0.18 ± 0.02	0.00 ± 0.12	0.19 ± 0.01	0.51 ± 0.01	0.00 ± 0.02	0.17 ± 0.16
	Nitrogen Trichloride	1.44 ± 0.01	1.96 ± 0.03	1.77 ± 0.19	3.23 ± 0.09	4.27 ± 0.13	3.59 ± 0.29
	Combined Chlorine	1.85 ± 0.05	2.17 ± 0.14	2.12 ± 0.22	4.05 ± 0.19	4.42 ± 0.18	4.04 ± 0.36
	Total Residual	2.08 ± 0.07	2.73 ± 0.14	3.03 ± 0.23	5.25 ± 0.20	5.39 ± 0.21	5.29 ± 0.44
D3	Free Chlorine	0.20 ± 0.03	0.54 ± 0.05	0.89 ± 0.04	1.21 ± 0.09	0.90 ± 0.07	1.09 ± 0.12
	Mono-Chloramine	0.20 ± 0.02	0.19 ± 0.01	0.18 ± 0.02	0.26 ± 0.02	0.21 ± 0.08	0.31 ± 0.09
	Di-chloramine	0.25 ± 0.04	0.14 ± 0.15	0.09 ± 0.02	0.01 ± 0.10	0.10 ± 0.01	0.00 ± 0.07
	Nitrogen Trichloride	1.56 ± 0.04	1.69 ± 0.10	1.85 ± 0.01	4.34 ± 0.34	4.07 ± 0.16	4.11 ± 0.39
	Combined Chlorine	2.01 ± 0.06	2.02 ± 0.18	2.12 ± 0.03	4.61 ± 0.35	4.38 ± 0.18	4.42 ± 0.41
	Total Residual	2.21 ± 0.07	2.56 ± 0.19	3.01 ± 0.05	5.82 ± 0.37	5.28 ± 0.19	5.51 ± 0.42

Table D2.2.2 (Continued) Summary of Chlorine Speciation Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L					
		October 9 1990			November 29 1990		
		T0	T1	T2	T0	T1	T2
E1	Free Chlorine	0.13 ± 0.03	0.23 ± 0.02	0.23 ± 0.03	0.86 ± 0.14	0.38 ± 0.01	0.47 ± 0.08
	Mono-Chloramine	0.32 ± 0.02	0.36 ± 0.02	0.44 ± 0.03	0.16 ± 0.14	0.30 ± 0.02	0.25 ± 0.06
	Di-chloramine	0.21 ± 0.10	0.07 ± 0.09	0.12 ± 0.06	0.01 ± 0.05	0.00 ± 0.12	0.03 ± 0.14
	Nitrogen Trichloride	3.61 ± 0.29	4.38 ± 0.00	4.63 ± 0.04	3.37 ± 0.20	4.03 ± 0.24	3.28 ± 0.44
	Combined Chlorine	4.14 ± 0.31	4.81 ± 0.09	5.19 ± 0.08	3.54 ± 0.25	4.03 ± 0.27	3.56 ± 0.47
	Total Residual	4.27 ± 0.31	5.04 ± 0.09	5.42 ± 0.08	4.40 ± 0.29	4.71 ± 0.27	4.03 ± 0.47
E2	Free Chlorine	0.14 ± 0.06	0.20 ± 0.03	0.19 ± 0.03	0.73 ± 0.01	0.39 ± 0.04	0.45 ± 0.14
	Mono-Chloramine	0.25 ± 0.08	0.37 ± 0.03	0.38 ± 0.02	0.31 ± 0.11	0.27 ± 0.05	0.20 ± 0.14
	Di-chloramine	0.23 ± 0.07	0.12 ± 0.06	0.18 ± 0.03	0.10 ± 0.04	0.08 ± 0.05	0.15 ± 0.12
	Nitrogen Trichloride	3.45 ± 0.03	4.12 ± 0.06	4.33 ± 0.04	3.25 ± 0.03	3.47 ± 0.14	3.17 ± 0.20
	Combined Chlorine	3.93 ± 0.11	4.61 ± 0.09	4.82 ± 0.05	3.66 ± 0.12	3.82 ± 0.15	3.52 ± 0.27
	Total Residual	4.07 ± 0.13	4.81 ± 0.09	5.01 ± 0.06	4.39 ± 0.12	4.21 ± 0.16	3.97 ± 0.31
E3	Free Chlorine	0.12 ± 0.07	0.14 ± 0.03	0.22 ± 0.03	0.87 ± 0.16	0.32 ± 0.07	1.11 ± 0.06
	Mono-Chloramine	0.28 ± 0.01	0.32 ± 0.05	0.40 ± 0.04	0.18 ± 0.19	0.24 ± 0.06	0.36 ± 0.05
	Di-chloramine	0.28 ± 0.11	0.03 ± 0.14	0.18 ± 0.11	0.09 ± 0.09	0.04 ± 0.03	0.09 ± 0.36
	Nitrogen Trichloride	3.50 ± 0.07	4.16 ± 0.26	4.31 ± 0.04	3.25 ± 0.03	3.55 ± 0.03	3.87 ± 0.60
	Combined Chlorine	4.06 ± 0.13	4.51 ± 0.30	4.89 ± 0.12	3.52 ± 0.21	3.83 ± 0.07	4.32 ± 0.70
	Total Residual	4.18 ± 0.15	4.65 ± 0.30	5.11 ± 0.13	4.39 ± 0.27	4.15 ± 0.10	5.43 ± 0.70

Table D2.2.3 Summary of Chlorine Speciation Results During the Summer and Fall Sampling at Pool II. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg Cl2 as Cl/L		
		July 7 1990	December 12 1990	
		(afternoon)	T0	T1
α1,2 & 3	Free Chlorine	1.01 ± 0.06	0.74 ± 0.08	1.18 ± 0.04
	Mono-Chloramine	0.59 ± 0.11	0.40 ± 0.12	0.25 ± 0.02
(α2)	Di-chloramine	1.03 ± 0.06	0.37 ± 0.04	0.40 ± 0.04
	Nitrogen Trichloride	2.87 ± 0.01	2.41 ± 0.14	2.19 ± 0.08
	Combined Chlorine	4.49 ± 0.13	3.18 ± 0.19	2.84 ± 0.09
	Total Residual	5.50 ± 0.14	3.92 ± 0.20	4.02 ± 0.10
β1,2 & 3	Free Chlorine	1.35 ± 0.02	1.57 ± 0.01	1.62 ± 0.05
	Mono-Chloramine	0.38 ± 0.01	0.31 ± 0.02	0.31 ± 0.07
(β2)	Di-chloramine	1.21 ± 0.32	0.44 ± 0.19	0.41 ± 0.23
	Nitrogen Trichloride	2.39 ± 0.41	2.25 ± 0.21	2.12 ± 0.28
	Combined Chlorine	3.98 ± 0.52	3.00 ± 0.28	2.84 ± 0.37
	Total Residual	5.33 ± 0.52	4.57 ± 0.28	4.46 ± 0.37
β4, 5 & 6	Free Chlorine	1.44 ± 0.38	1.53 ± 0.08	1.37 ± 0.13
	Mono-Chloramine	0.41 ± 0.25	0.37 ± 0.09	0.24 ± 0.04
(β5)	Di-chloramine	1.39 ± 0.24	0.40 ± 0.12	0.32 ± 0.18
	Nitrogen Trichloride	1.88 ± 1.82	2.27 ± 0.17	2.30 ± 2.20
	Combined Chlorine	3.68 ± 1.85	3.04 ± 0.23	2.86 ± 2.21
	Total Residual	5.12 ± 1.89	4.57 ± 0.24	4.23 ± 2.21
β7, 8 & 9	Free Chlorine		1.65 ± 0.08	2.13 ± 0.08
	Mono-Chloramine		0.24 ± 0.12	0.13 ± 0.05
	Di-chloramine		0.36 ± 0.13	0.62 ± 0.11
	Nitrogen Trichloride		2.11 ± 0.27	1.89 ± 0.21
	Combined Chlorine		2.71 ± 0.32	2.64 ± 0.24
	Total Residual		4.36 ± 0.33	4.77 ± 0.26
β10, 11 & 12	Free Chlorine	1.18 ± 0.11	1.84 ± 0.10	2.01 ± 0.05
	Mono-Chloramine	0.58 ± 0.15	0.35 ± 0.10	0.35 ± 0.12
(β11)	Di-chloramine	1.35 ± 0.24	0.41 ± 0.15	0.48 ± 0.13
	Nitrogen Trichloride	2.26 ± 0.64	2.21 ± 0.22	2.33 ± 0.03
	Combined Chlorine	4.19 ± 0.70	2.97 ± 0.28	3.16 ± 0.18
	Total Residual	5.37 ± 0.71	4.81 ± 0.30	5.17 ± 0.19

Table D2.2.3 (Continued) Summary of Chlorine Speciation Results During the Summer and Fall Sampling at Pool II. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg Cl2 as Cl/L		
		July 7 1990	December 12 1990	
		(afternoon)	T0	T1
β13, 14 & 15	Free Chlorine		1.99 ± 0.23	1.88 ± 0.03
	Mono-Chloramine		0.20 ± 0.18	0.33 ± 0.05
	Di-chloramine		0.47 ± 0.14	0.24 ± 0.11
	Nitrogen Trichloride		2.12 ± 0.42	2.51 ± 0.18
	Combined Chlorine		2.79 ± 0.48	3.08 ± 0.22
	Total Residual		4.78 ± 0.53	4.96 ± 0.22
β16, 17 & 18	Free Chlorine	1.15 ± 0.16	1.63 ± 0.19	2.17 ± 0.02
	Mono-Chloramine	0.50 ± 0.04	0.20 ± 0.19	0.34 ± 0.06
(β17)	Di-chloramine	0.88 ± 0.20	0.56 ± 0.07	0.29 ± 0.15
	Nitrogen Trichloride	2.60 ± 0.13	1.95 ± 0.40	2.38 ± 0.15
	Combined Chlorine	3.98 ± 0.24	2.71 ± 0.45	3.01 ± 0.22
	Total Residual	5.13 ± 0.29	4.34 ± 0.49	5.18 ± 0.22
χ1, 2 & 3	Free Chlorine	0.07 ± 0.12	0.22 ± 0.02	0.13 ± 0.01
	Mono-Chloramine	0.50 ± 0.17	0.40 ± 0.07	0.39 ± 0.05
(χ2)	Di-chloramine	2.69 ± 0.70	0.60 ± 0.09	0.73 ± 0.08
	Nitrogen Trichloride	4.15 ± 1.66	3.71 ± 0.25	4.02 ± 0.13
	Combined Chlorine	7.34 ± 1.81	4.71 ± 0.27	5.14 ± 0.16
	Total Residual	7.41 ± 1.81	4.93 ± 0.28	5.27 ± 0.16
δ1, 2 & 3	Free Chlorine	0.00 ± 0.00	1.49 ± 0.04	0.15 ± 0.02
	Mono-Chloramine	0.43 ± 0.05	0.28 ± 0.06	0.42 ± 0.11
(δ2)	Di-chloramine	1.89 ± 0.13	0.22 ± 0.12	0.55 ± 0.11
	Nitrogen Trichloride	4.07 ± 0.47	2.42 ± 0.06	3.66 ± 0.10
	Combined Chlorine	6.39 ± 0.49	2.92 ± 0.15	4.63 ± 0.18
	Total Residual	6.39 ± 0.49	4.41 ± 0.15	4.78 ± 0.19

Table D2.2.4 Summary of Chlorine Speciation Results During the Summer and Fall Sampling at Pool III. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L			
		July 5 (Afternoon)	December 5 1990		
			T0	T1	T2
X1	Free Chlorine		2.42 ± 0.03	2.30 ± 0.01	2.19 ± 0.07
	Mono-Chloramine		0.13 ± 0.02	0.06 ± 0.08	0.02 ± 0.04
	Di-chloramine		0.01 ± 0.10	0.91 ± NA	0.25 ± 0.41
	Nitrogen Trichloride		1.76 ± 0.07	0.08 ± NA	1.41 ± 0.35
	Combined Chlorine		1.90 ± 0.12	1.05 ± NA	1.68 ± 0.54
	Total Residual		4.32 ± 0.13	3.35 ± NA	3.87 ± 0.55
X2	Free Chlorine	1.79 ± 0.24	2.50 ± 0.44	2.17 ± 0.06	2.23 ± 0.08
	Mono-Chloramine	0.08 ± 0.13	0.13 ± 0.02	0.14 ± 0.05	0.04 ± 0.06
	Di-chloramine	0.42 ± 0.30	0.00 ± 0.13	0.38 ± 0.10	0.35 ± 0.05
	Nitrogen Trichloride	1.21 ± 1.02	1.21 ± 1.05	1.39 ± 0.03	1.22 ± 0.14
	Combined Chlorine	1.71 ± 1.07	1.34 ± 1.06	1.91 ± 0.12	1.61 ± 0.16
	Total Residual	3.50 ± 1.10	3.84 ± 1.15	4.08 ± 0.13	3.84 ± 0.18
X3	Free Chlorine		2.43 ± 0.04	2.09 ± 0.05	1.83 ± 0.13
	Mono-Chloramine		0.06 ± 0.50	0.10 ± 0.09	0.08 ± 0.07
	Di-chloramine		0.28 ± 0.50	0.25 ± 0.11	0.31 ± 0.11
	Nitrogen Trichloride		1.02 ± 1.07	1.36 ± 0.25	1.43 ± 0.20
	Combined Chlorine		1.36 ± 1.28	1.71 ± 0.29	1.82 ± 0.24
	Total Residual		3.79 ± 1.28	3.80 ± 0.29	3.65 ± 0.27
X4	Free Chlorine		2.27 ± 0.05	2.16 ± 0.07	2.14 ± 0.02
	Mono-Chloramine		0.11 ± 0.05	0.16 ± 0.03	0.12 ± 0.02
	Di-chloramine		0.04 ± 0.04	0.32 ± 0.10	0.28 ± 0.15
	Nitrogen Trichloride		1.61 ± 0.23	1.43 ± 0.29	1.45 ± 0.12
	Combined Chlorine		1.76 ± 0.24	1.91 ± 0.31	1.85 ± 0.19
	Total Residual		4.03 ± 0.24	4.07 ± 0.32	3.99 ± 0.19
X5	Free Chlorine		2.22 ± 0.04	2.24 ± 0.12	1.95 ± 0.13
	Mono-Chloramine		0.13 ± 0.05	0.00 ± 0.00	0.05 ± 0.08
	Di-chloramine		0.14 ± 0.28	0.39 ± 0.09	0.13 ± 0.23
	Nitrogen Trichloride		1.55 ± 0.52	1.06 ± 0.12	1.65 ± 0.03
	Combined Chlorine		1.82 ± 0.59	1.45 ± 0.15	1.83 ± 0.25
	Total Residual		4.04 ± 0.59	3.69 ± 0.19	3.78 ± 0.28

Table D2.2.4 (Continued) Summary of Chlorine Speciation Results During the Summer and Fall Sampling at Pool III. Study of Pool Profiles and Time Profiles.

Sample Identification	Chlorine Speciation	Average Concentration in mg of Cl2 as Cl/L			
		July 5 (Afternoon)	December 5 1990		
			T0	T1	T2
Y1	Free Chlorine		2.36 ± 0.10	2.29 ± 0.03	2.15 ± 0.02
	Mono-Chloramine		0.10 ± 0.08	0.00 ± 0.00	0.11 ± 0.01
	Di-chloramine		0.30 ± 0.04	0.42 ± 0.14	0.66 ± 0.48
	Nitrogen Trichloride		1.33 ± 0.42	1.06 ± 0.46	1.05 ± 0.30
	Combined Chlorine		1.73 ± 0.43	1.48 ± 0.48	1.82 ± 0.57
	Total Residual		4.09 ± 0.44	3.77 ± 0.48	3.97 ± 0.57
Y2	Free Chlorine	1.87 ± 0.05	2.30 ± 0.02	2.32 ± 0.04	2.22 ± 0.07
	Mono-Chloramine	0.25 ± 0.25	0.13 ± 0.01	0.07 ± 0.06	0.11 ± 0.13
	Di-chloramine	0.63 ± 0.13	0.16 ± 0.03	0.29 ± 0.11	0.27 ± 0.14
	Nitrogen Trichloride	0.64 ± 0.17	1.53 ± 0.09	1.27 ± 0.04	1.34 ± 0.35
	Combined Chlorine	1.52 ± 0.33	1.82 ± 0.10	1.63 ± 0.13	1.72 ± 0.40
	Total Residual	3.39 ± 0.33	4.12 ± 0.10	3.95 ± 0.14	3.94 ± 0.40
Y3	Free Chlorine		2.32 ± 0.07	2.35 ± 0.15	1.98 ± 0.05
	Mono-Chloramine		0.11 ± 0.12	0.08 ± 0.07	0.07 ± 0.07
	Di-chloramine		0.42 ± 0.14	0.42 ± 0.13	0.19 ± 0.17
	Nitrogen Trichloride		1.34 ± 0.23	1.05 ± 0.68	1.53 ± 0.00
	Combined Chlorine		1.87 ± 0.29	1.55 ± 0.70	1.79 ± 0.18
	Total Residual		4.19 ± 0.30	3.90 ± 7.10	3.77 ± 0.19
Y4	Free Chlorine		2.42 ± 0.20	1.94 ± 0.12	1.94 ± 0.09
	Mono-Chloramine		0.10 ± 0.09	0.06 ± 0.10	0.04 ± 0.08
	Di-chloramine		0.24 ± 0.09	0.41 ± 0.12	0.21 ± 0.15
	Nitrogen Trichloride		1.26 ± 0.06	1.16 ± 0.17	1.43 ± 0.03
	Combined Chlorine		1.60 ± 0.14	1.63 ± 0.23	1.68 ± 0.17
	Total Residual		4.02 ± 0.24	3.57 ± 0.26	3.62 ± 0.19
Y5	Free Chlorine		2.32 ± 0.11	2.31 ± 0.06	2.21 ± 0.07
	Mono-Chloramine		0.17 ± 0.15	0.00 ± 0.00	0.02 ± 0.04
	Di-chloramine		0.20 ± 0.20	0.53 ± 0.09	0.06 ± 0.14
	Nitrogen Trichloride		1.43 ± 0.00	0.93 ± 0.01	1.78 ± 0.42
	Combined Chlorine		1.80 ± 0.25	1.46 ± 0.09	1.86 ± 0.44
	Total Residual		4.12 ± 0.27	3.77 ± 0.11	4.07 ± 0.45

Table D2.2.4 (Continued) Summary of Chlorine Speciation Results During the Summer and Fall Sampling at Pool III. Study of Pool Profiles and Time Profiles.

Sample Identification	**Chlorine Speciation**	**Average Concentration in mg of Cl2 as Cl/L**			
		July 5 (Afternoon)	**December 5 1990**		
			T0	**T1**	**T2**
Z1	Free Chlorine		2.11 ± 0.30	2.31 ± 0.06	2.48 ± 0.43
	Mono-Chloramine		0.01 ± 0.01	0.08 ± 0.07	0.04 ± 0.06
	Di-chloramine		0.36 ± 0.37	0.15 ± 0.20	0.30 ± 0.01
	Nitrogen Trichloride		1.01 ± 0.76	1.42 ± 0.39	1.27 ± 0.16
	Combined Chlorine		1.38 ± 0.85	1.65 ± 0.44	1.61 ± 0.17
	Total Residual		3.49 ± 0.90	3.96 ± 0.45	4.09 ± 0.46
Z2	Free Chlorine		2.20 ± 0.08	2.37 ± 0.05	2.12 ± 0.03
	Mono-Chloramine		0.07 ± 0.07	0.03 ± 0.05	0.15 ± 0.04
	Di-chloramine		0.12 ± 0.02	0.31 ± 0.24	0.28 ± 0.04
	Nitrogen Trichloride		1.42 ± 0.01	1.34 ± 0.03	1.69 ± 0.14
	Combined Chlorine		1.61 ± 0.07	1.68 ± 0.25	2.12 ± 0.15
	Total Residual		3.81 ± 0.11	4.05 ± 0.25	4.24 ± 0.15
Z3	Free Chlorine	1.86 ± 0.05	2.10 ± 0.11	2.31 ± 0.02	2.11 ± 0.04
	Mono-Chloramine	0.12 ± 0.11	0.09 ± 0.04	0.14 ± 0.02	0.13 ± 0.01
(Z3:4)	Di-chloramine	0.44 ± 0.10	0.31 ± 0.43	0.39 ± 0.14	0.25 ± 0.01
	Nitrogen Trichloride	0.68 ± 0.06	1.28 ± 0.52	1.40 ± 0.13	1.51 ± 0.12
	Combined Chlorine	1.24 ± 0.16	1.68 ± 0.68	1.93 ± 0.19	1.89 ± 0.12
	Total Residual	3.10 ± 0.17	3.78 ± 0.68	4.24 ± 0.19	4.00 ± 0.13
Z4	Free Chlorine		2.23 ± 0.11	2.37 ± 0.07	2.24 ± 0.05
	Mono-Chloramine		0.12 ± 0.11	0.02 ± 0.04	0.03 ± 0.06
	Di-chloramine		0.32 ± 0.14	0.41 ± 0.16	0.14 ± 0.05
	Combined Chlorine		1.16 ± 0.46	1.26 ± 0.14	1.42 ± 0.04
	Total Residual		1.60 ± 0.49	1.69 ± 0.22	1.59 ± 0.09
			3.83 ± 0.51	4.06 ± 0.23	3.83 ± 0.10
Z5	Free Chlorine	1.89 ± 0.11	2.15 ± 0.11	2.16 ± 0.05	2.17 ± 0.15
	Mono-Chloramine	0.16 ± 0.15	0.18 ± 0.04	0.09 ± 0.08	0.04 ± 0.08
(Z1:5)	Di-chloramine	0.56 ± 0.02	0.33 ± 0.17	0.46 ± 0.19	0.46 ± 0.01
	Nitrogen Trichloride	0.62 ± 0.03	1.39 ± 0.43	1.42 ± 0.25	0.98 ± 0.09
	Combined Chlorine	1.34 ± 0.15	1.90 ± 0.46	1.97 ± 0.32	1.48 ± 0.12
	Total Residual	3.23 ± 0.19	4.05 ± 0.48	4.13 ± 0.33	3.65 ± 0.19
TAP WATER	Free Chlorine				2.34 ± 0.02
	Mono-Chloramine				0.00 ± 0.00
(Afternoon)	Di-chloramine				0.38 ± 0.06
	Nitrogen Trichloride				1.21 ± 0.10
	Combined Chlorine				1.59 ± 0.12
	Total Residual				3.93 ± 0.12

APPENDIX D3

Trihalomethanes

APPENDIX D3.1

Instrument Operating Parameters

APPENDIX D3.1 Instrument Operating Parameters

Tables D.3.1 and D.3.2 list instrument operating parameters used for the trihalomethane analyses. Slight modification of the parameters had to be used following replacement of the "6 ports valve" and of the Tenax packing in the LSC-2 part of the Tekmar instrument and cleanout of the flame ionization tip on the GC Varian 3300. Mechanical failure of the "6 port valve" created some problem from the middle of August 1990 to the middle of December of the same year. Multiple attempt in reestablishing a stable baseline response were conducted, several run of different standard concentration were ran, flame ionization tip was cleaned, system was checked for leaks and Tenax packing was replaced. Finally, clean-out run and bake out at each tube had to be lengthened up to 30 minutes from 16 minutes in order to obtain a stable baseline. Calibration curve were repeated in January of 1991 and quality control concentration was increased to 40 ppb from 20 ppb before all the modification. The latter increase was to eliminate possible baseline artefacts, the concentration chosen was also closer to the general concentration obtained with most samples. Previous calibration curves had been ran in July of 1990 and March 1989, response factor and retention time remained comparable.

Table D3.1 Instrument Operating Parameters for EPA (1984) Method 501.1

Purge and Trap Sampler: Tekmar LSC-2 concentrator interfaced with ALS autosampler.

ALS autosampler

Purge Time: 11 min.
Desorb Time: 4 min.
Bake Time: 16 min. (until modification, after modification 30 min.)
Transfer Lines (T°C): 140°C
Purge Gas Flow Rate, Nitrogen: 40 mL/min.
Desorb Ready & Desorb Preheat Toggle @ Hold
Bake Toggle @ Auto
Thermocouple Toggles @ Interfaced (ON)
Trap Material: Tenax TA (60/80 mesh)

LSC-2 Interface Set Points

Purge Volume: 5 mL of sample (or standard)
SP1 (Trap): 30°C
SP2 (Column T°C at Start of GC run): 61°C
SP3 (Trap Preheat): 100°C
SP4 (Desorb Time): 180°C
SP5 (Trap Bake T°C): 225°C

Gas Chromatograph: Varian Model 3300

Packed Column: 1% SP1000 on Carbopack B (60/80 mesh), 3 m x 0.25 cm.

GC Temperatures: Injection Port: 150°C
Column: Hold at 60°C for 0.5 min.;
Increase at 6°C/min.;
Hold at 210°C for 5 min.
Detector: 300°C

Carrier Gas: Nitrogen: 30 mL/min.
3 mL/min. to injector
27 mL/min. directly to column

Detector: Flame Ionization
Hydrogen flow: 30 mL/min.
Air flow: 240 mL.min.

Integrator: Spectra-Physics model SP-4290

Table D3.2 Clean-Out Procedure

Purge and Trap Sampler: Tekmar LSC-2 concentrator interfaced with ALS autosampler.

ALS autosampler: All parameters are the same as for run except:

Purge Time: 10 min.
Desorb Time: 00 min.
Bake time: 16 min. (until modification, after modification 30 min.)
Desorb Ready & Desorb Preheat Toggle @ Auto
Bake Toggle @ Reset*
Thermocouple Toggles @ Disconnected (OFF)

LSC-2 Interface Set Points: All parameters are the same as for run except:

Purge Volume: 5 mL of organic free water
SP-1 (Trap): 98°C

Gas Chromatograph: All parameters are the same as for run except:

GC Temperatures: Injection Port: 175°C
Column: Hold at 210°C for 0.5 min.;
Increase at 6°C/min.;
Hold at 211°C for 5 min.
Detector: 350°C

*After the #10 has finished, switch bake toggle to Auto, step LSC through to bake, and bake out Tenax column for 16 min. (16 min. was used until modification than 30 min. had to be used to ensure proper bake out of the Tenax).

APPENDIX D3.2

Trihalomethanes Calibration Curves

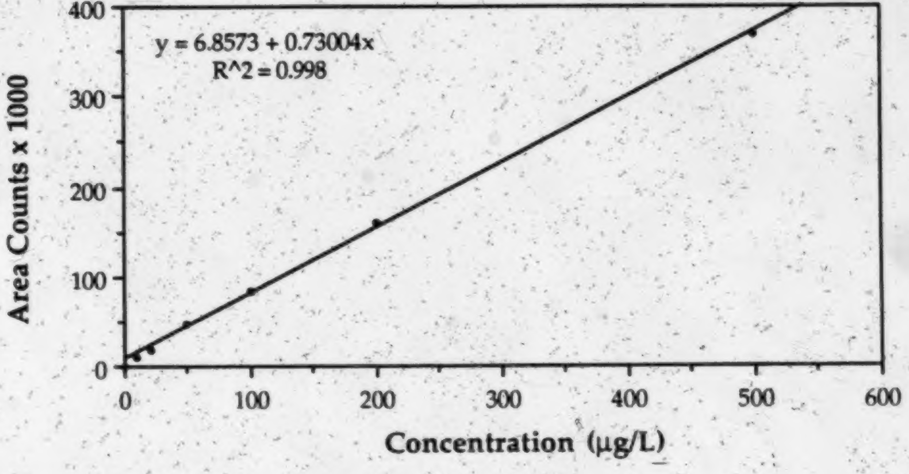


Figure D3.2.1 Chloroform Calibration Curve-July 22, 1990.

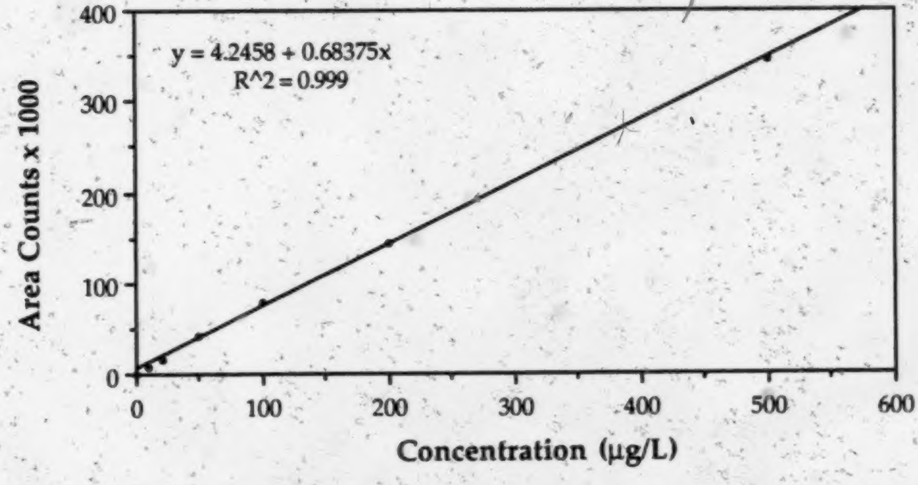


Figure D3.2.2 Bromodichloromethane Calibration Curve-July 22, 1990.

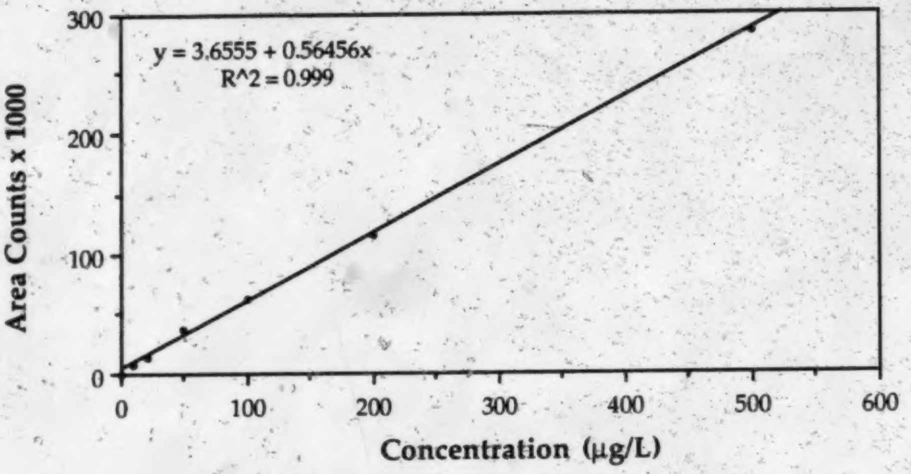


Figure D3.2.3 Dibromochloromethane Calibration Curve-July 22, 1990.

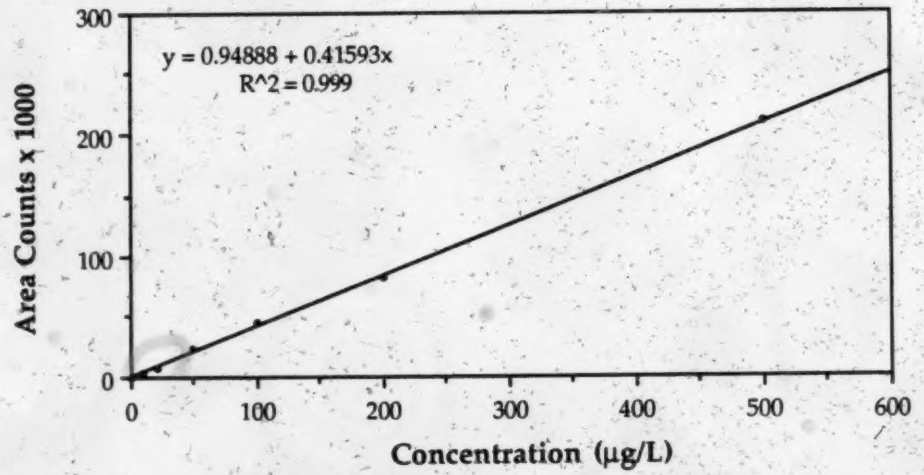


Figure D3.2.4 Bromoform Calibration Curve-July 22, 1990.

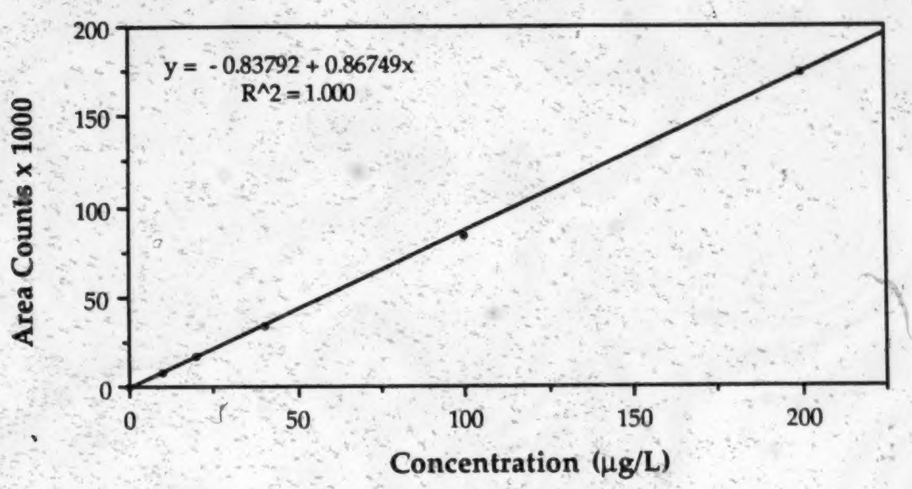


Figure D3.2.5 Chloroform Calibration Curve-January 15, 1991.

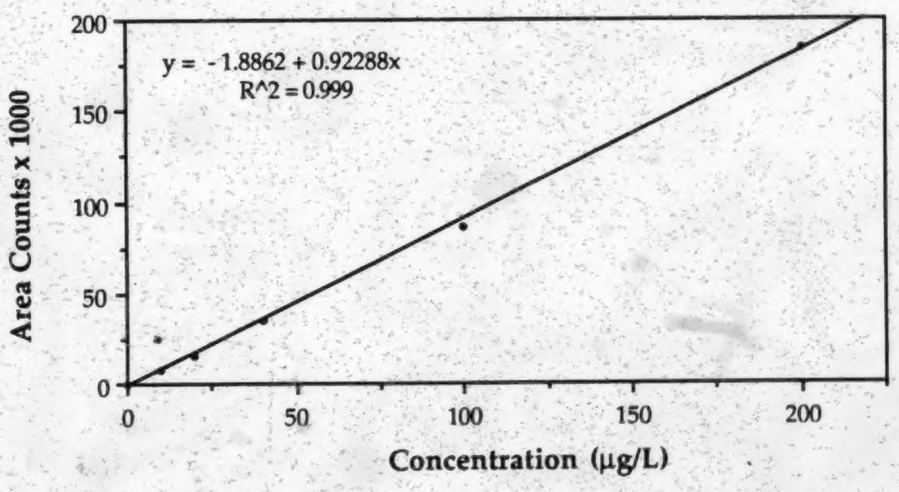


Figure D3.2.6 Bromodichloromethane Calibration Curve-January 15, 1991.

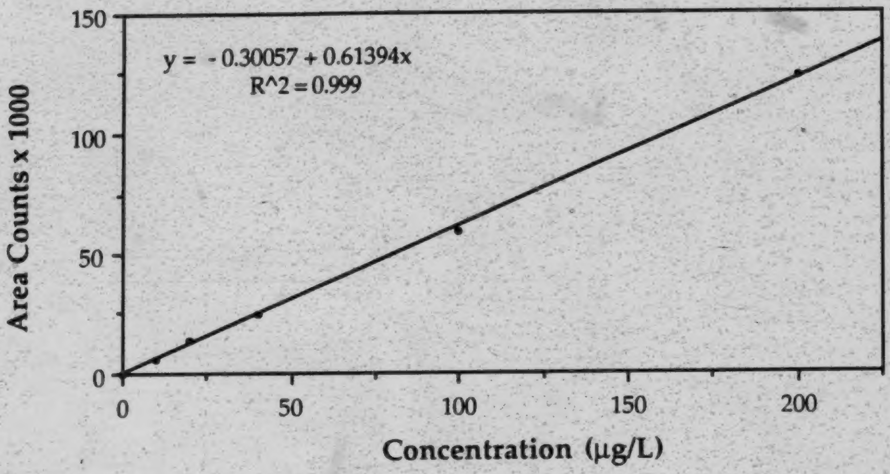


Figure D3.2.7 Dibromochloromethane Calibration Curve-January 15, 1991.

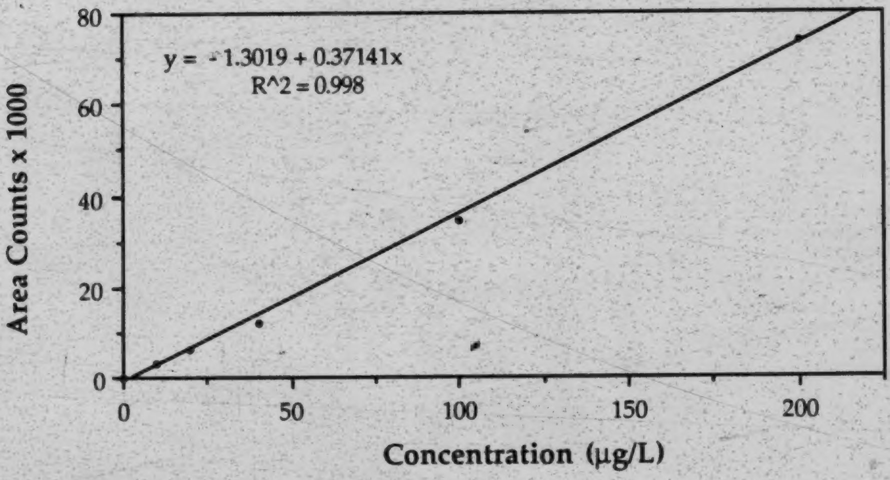


Figure D3.2.8 Bromoform Calibration Curve-January 15, 1991.

APPENDIX D3.3

Trihalomethanes Quality Control Charts

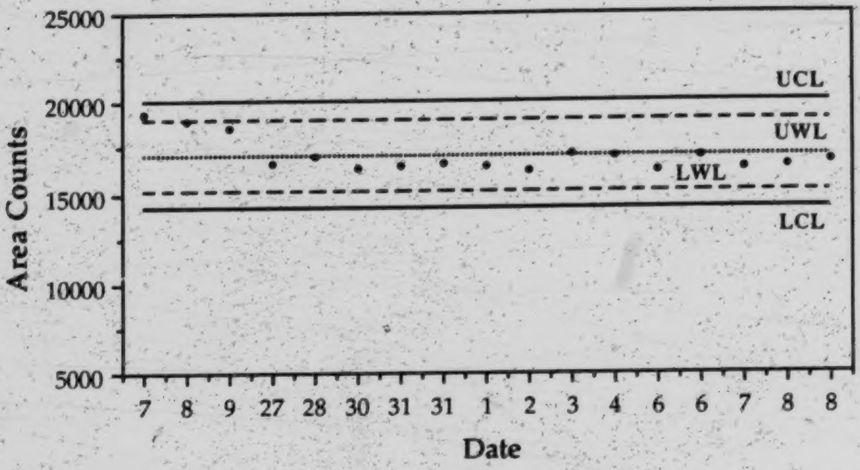


Figure D3.3.1 Chloroform Quality Control Chart, July and August, 1990.

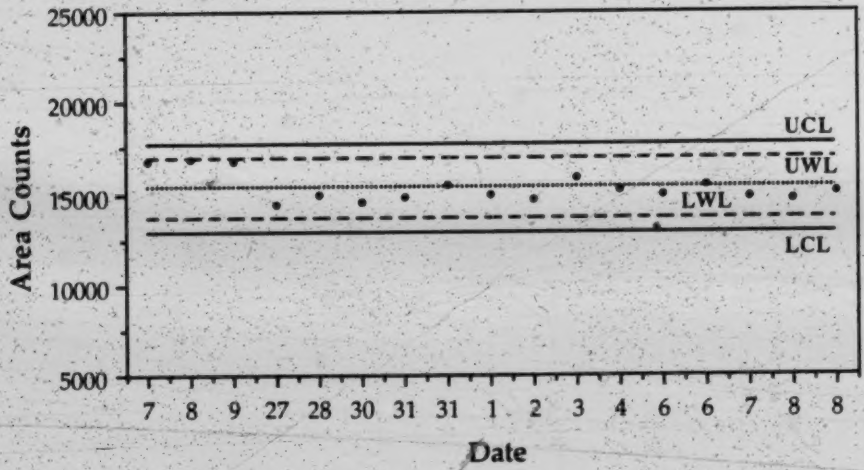


Figure D3.3.2 Bromodichloromethane Quality Control Chart, July and August, 1990.

✓

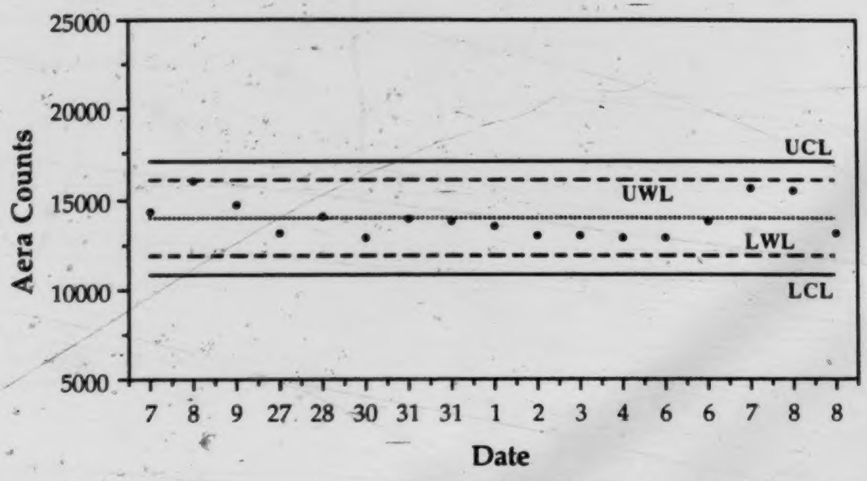


Figure D3.3.3 Dibromochloromethane Quality Control Chart, July and August, 1990.

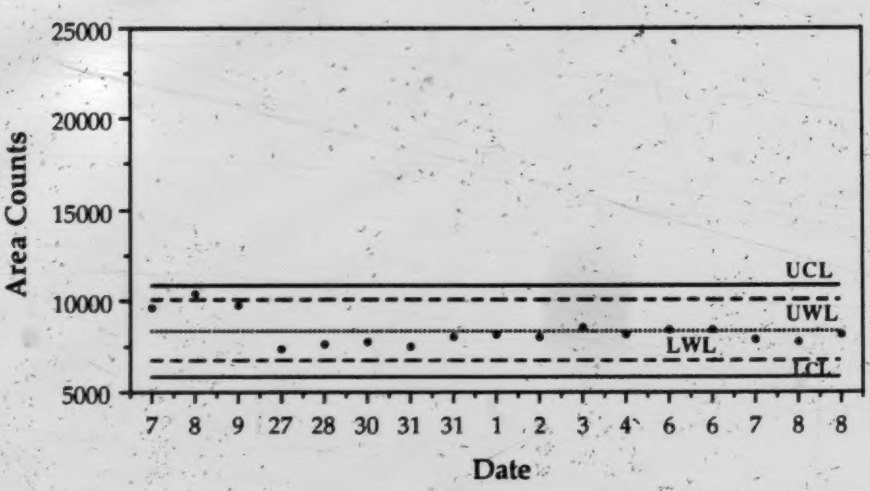


Figure D3.3.4 Bromoform Quality Control Chart, July and August, 1990.

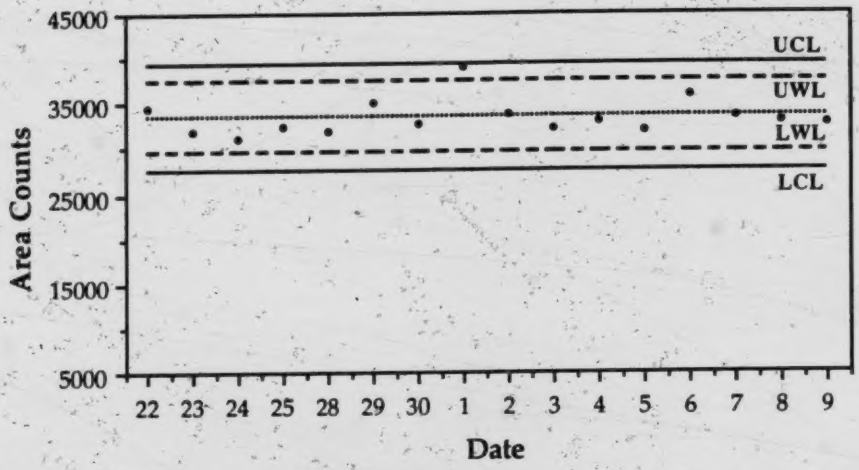


Figure D3.3.5 Chloroform Quality Control Chart, December, 1990 and January, 1991.

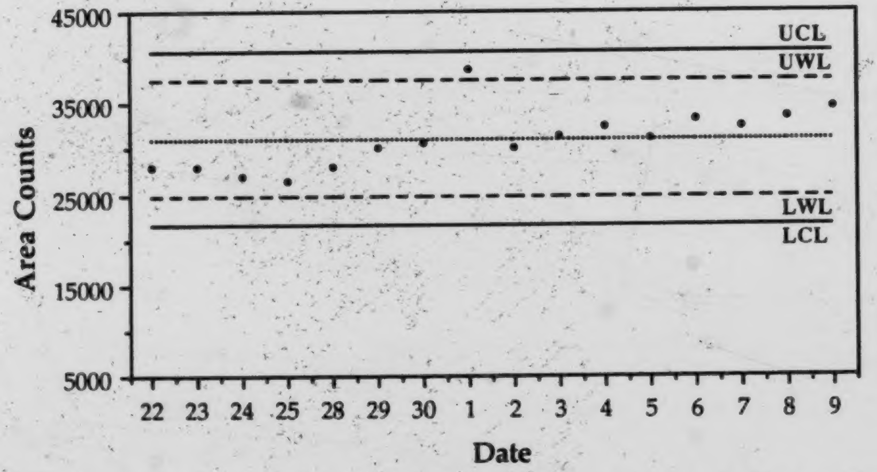


Figure D3.3.6 Bromodichloromethane Quality Control Chart, December, 1990 and January, 1991.

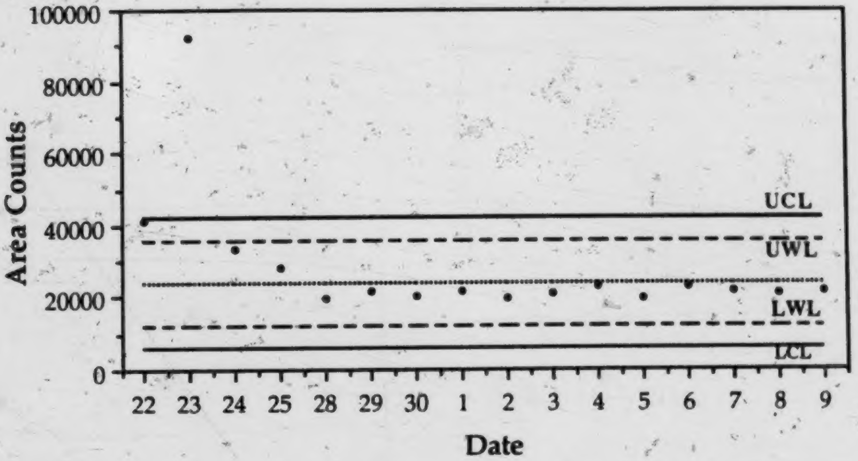


Figure D3.3.7 Dibromochloromethane Quality Control Chart, December, 1990 and January, 1991.

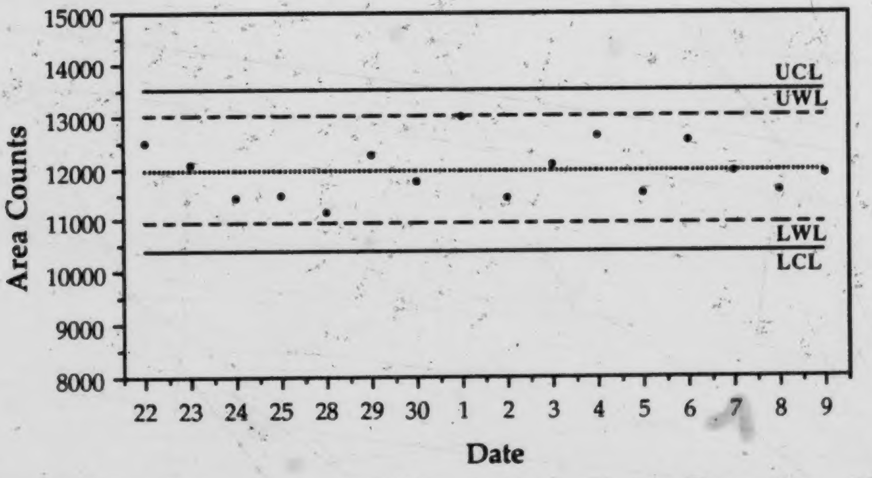


Figure D3.3.8 Bromoform Quality Control Chart, December, 1990 and January, 1991.

APPENDIX D3.4

Trihalomethane Analysis Results

Table D3.4.1 Summary of Trihalomethane Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	Trihalomethane Concentration in µg/L							
	July 26 1990				July 30 1990			
	CHCl3	CHCl2Br	CHClBr2	CHBr3	CHCl3	CHCl2Br	CHClBr2	CHBr3
A1	42.59 ± 0.56	2.94 ± 0.06	15.86 ± 6.50	0.00 ± 0.00	45.64 ± 2.10	2.89 ± 0.04	10.47 ± 2.88	0.00 ± 0.00
A2					46.17 ± 0.91	3.37 ± 0.28	14.40 ± 0.78	0.00 ± 0.00
A3					47.08 ± 2.86	3.45 ± 0.30	14.70 ± 0.13	0.00 ± 0.00
B1	71.45 ± 1.31	3.26 ± 0.03	11.09 ± 2.17	0.00 ± 0.00	69.97 ± 0.41	3.83 ± 0.83	9.39 ± 0.11	0.00 ± 0.00
B2					66.78 ± 2.98	3.25 ± 0.04	10.63 ± 0.36	0.00 ± 0.00
B3					69.43 ± 4.39	3.74 ± 0.32	11.56 ± 0.40	0.00 ± 0.00
C1	87.03 ± 1.15	4.19 ± 0.50	33.07 ± 1.07	0.00 ± 0.00	84.86 ± 1.69	4.40 ± 0.19	30.19 ± 1.65	0.00 ± 0.00
C2					79.89 ± 2.72	3.89 ± 0.06	35.68 ± 0.18	0.00 ± 0.00
C3					80.63 ± 5.47	4.88 ± 0.11	31.11 ± 1.30	0.00 ± 0.00
D1	89.86 ± 1.65	4.05 ± 0.04	29.27 ± 7.47	0.00 ± 0.00	85.78 ± 3.24	4.09 ± 0.07	36.49 ± 0.29	0.00 ± 0.00
D2					82.00 ± 5.73	3.71 ± 0.11	21.32 ± 1.09	0.00 ± 0.00
D3					86.50 ± 4.77	4.01 ± 0.18	26.88 ± 1.97	0.00 ± 0.00
E1	168.99 ± 2.49	6.57 ± 0.14	113.70 ± 11.72	0.00 ± 0.00	89.16 ± 0.47	3.12 ± 0.02	59.39 ± 3.43	0.00 ± 0.00
E2					88.84 ± 6.90	3.29 ± 0.12	44.39 ± 0.87	0.00 ± 0.00
E3					89.52 ± 6.19	2.88 ± 0.18	49.81 ± 3.63	0.00 ± 0.00

Table D3.4.1 (Continued) Summary of Trihalomethane Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	Trihalomethane Concentration in µg/L							
	August 1 1990				August 6 1990			
	CHCl3	CHCl2Br	CHClBr2		CHCl3	CHCl2Br	CHClBr2	CHBr3
A1	43.80 ± 1.72	3.87 ± 0.28	13.82 ± 4.22	0.00 ± 0.00	54.38 ± NA	3.60 ± NA	13.55 ± NA	0.00 ± NA
A2	44.28 ± 0.83	3.89 ± 0.22	13.94 ± 0.73	0.00 ± 0.00	57.06 ± 2.98	3.41 ± 0.13	18.94 ± 0.64	0.00 ± 0.00
A3	43.28 ± 3.08	2.78 ± 0.11	12.83 ± 4.41	0.00 ± 0.00	56.50 ± 2.88	3.45 ± 0.03	11.76 ± 0.83	0.00 ± 0.00
B1	68.60 ± 7.48	7.38 ± 5.49	8.78 ± 0.45	0.00 ± 0.00	69.73 ± 3.95	4.08 ± 0.11	11.54 ± 0.59	0.00 ± 0.00
B2	73.57 ± 4.89	3.64 ± 0.47	17.07 ± 10.14	0.00 ± 0.00	72.14 ± 3.13	3.48 ± 0.14	13.31 ± 0.39	0.00 ± 0.00
B3	69.53 ± 6.38	5.22 ± 0.55	11.81 ± 0.56	0.00 ± 0.00	73.86 ± 2.84	3.52 ± 0.02	14.46 ± 0.99	0.00 ± 0.00
C1	79.52 ± 3.95	3.88 ± 0.30	20.87 ± 5.53	0.00 ± 0.00	85.55 ± 2.62	3.86 ± 0.02	13.19 ± 5.07	0.00 ± 0.00
C2	79.72 ± NA	4.42 ± NA	30.21 ± NA	0.00 ± NA	79.08 ± 1.59	3.66 ± 0.01	40.33 ± 1.21	0.00 ± 0.00
C3	78.24 ± 4.45	9.30 ± 2.32	30.77 ± 0.04	0.00 ± 0.00	85.73 ± 3.08	3.80 ± 0.06	34.97 ± 1.17	0.00 ± 0.00
D1	77.79 ± 2.62	4.09 ± 0.34	29.99 ± 2.77	0.00 ± 0.00	85.69 ± 5.05	3.87 ± 0.12	36.57 ± 1.17	0.00 ± 0.00
D2	76.70 ± 4.94	6.43 ± 1.86	36.54 ± 4.35	0.00 ± 0.00	81.06 ± 4.35	4.18 ± 0.22	36.11 ± 3.91	0.00 ± 0.00
D3	79.75 ± 7.26	3.89 ± 0.33	25.15 ± 3.45	0.00 ± 0.00	83.35 ± 2.45	3.81 ± 0.12	27.83 ± 2.61	0.00 ± 0.00
E1	101.03 ± 6.52	4.61 ± 0.87	73.41 ± 7.47	0.00 ± 0.00	149.77 ± 5.27	3.59 ± 0.19	108.62 ± 4.78	0.00 ± 0.00
E2	100.19 ± 9.09	4.80 ± 1.29	71.27 ± 4.67	0.00 ± 0.00	127.49 ± 5.44	3.43 ± 0.04	101.52 ± 1.99	0.00 ± 0.00
E3	98.71 ± 8.76	5.82 ± 0.20	68.81 ± 1.34	0.00 ± 0.00	133.37 ± 0.87	3.44 ± 0.11	95.59 ± 5.13	0.00 ± 0.00

Table D3.4.2 Summary of Trihalomethane Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles.

Sample Identification	Trihalomethane Concentration in µg/L							
	Time Profile on October 9 1990				Time Profile on November 29 1990			
	CHCl3	CHCl2Br	CHClBr2	CHBr3	CHCl3	CHCl2Br	CHClBr2	CHBr3
T0 A1, 2 & 3	57.63 ± 2.21	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	72.47 ± 1.29	0.00 ± 0.00	5.00 ± 7.06	0.00 ± 0.00
T1 A1, 2 & 3	68.14 ± 7.57	0.00 ± 0.00	75.46 ± 5.59	0.00 ± 0.00	68.67 ± 3.16	2.21 ± 3.12	709.69 ± 1.14	0.00 ± 0.00
T2 A1, 2 & 3	52.50 ± 1.63	0.00 ± 0.00	13.41 ± 7.38	0.00 ± 0.00	67.82 ± 1.20	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T0 B1, 2 & 3	54.47 ± 0.10	0.00 ± 0.00	8.95 ± 0.71	0.00 ± 0.00	64.08 ± 0.47	0.00 ± 0.00	3.18 ± 4.49	0.00 ± 0.00
T1 B1, 2 & 3	55.23 ± 0.92	0.00 ± 0.00	7.07 ± 1.00	0.00 ± 0.00	65.61 ± 2.88	3.49 ± 0.07	0.00 ± 0.00	0.00 ± 0.00
T2 B1, 2 & 3	50.81 ± 2.57	0.00 ± 0.00	4.03 ± 5.69	0.00 ± 0.00	65.22 ± 3.81	0.00 ± 0.00	1.32 ± 1.86	0.00 ± 0.00
T0 C1, 2 & 3	185.58 ± 1.53	0.00 ± 0.00	703.06 ± 8.87	0.00 ± 0.00	89.43 ± 1.65	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 C1, 2 & 3	69.16 ± 7.75	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	75.58 ± 1.43	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T2 C1, 2 & 3	361.89 ± 5.01	0.00 ± 0.00	1444.63 ± 1.60	0.00 ± 0.00	80.08 ± 1.48	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T0 D1, 2 & 3	440.17 ± 0.18	0.00 ± 0.00	2110.78 ± 1.87	0.00 ± 0.00	103.46 ± 1.69	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 D1, 2 & 3	71.43 ± 1.20	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	75.18 ± 0.81	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T2 D1, 2 & 3	66.24 ± 1.05	3.70 ± 0.30	0.00 ± 0.00	0.00 ± 0.00	80.77 ± 0.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T0 E1, 2 & 3	74.21 ± 3.72	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	58.29 ± NA	0.00 ± NA	0.00 ± NA	0.00 ± NA
T1 E1, 2 & 3	115.79 ± 1.10	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	48.86 ± 2.11	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T2 E1, 2 & 3	103.38 ± 1.69	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	48.62 ± 1.11	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Comments: NA: Not Available, since results based on a single analysis.

Table D3.4.3 Summary of Trihalomethane Results During the Summer and Fall Sampling at Pool II. Study of Pool Profiles and Time Profiles.

Sample Identification	Trihalomethane Concentration in µg/L							
	(Afternoon Sampling July 7, 1990)				Time Profile on December 12, 1990			
	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$
T0 α1, 2 & 3 (α2)	52.80 ± NA	3.41 ± NA	66.14 ± NA	0.00 ± NA	45.58 ± 5.13	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 α1, 2 & 3					28.35 ± 2.60	3.25 ± 0.16	0.00 ± 0.00	0.00 ± 0.00
T0 β1, 2 & 3 (β2)	64.15 ± 0.30	6.26 ± 0.50	64.84 ± 10.33	0.00 ± 0.00	51.98 ± 10.05	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 β1, 2 & 3					40.05 ± 2.64	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T0 β4, 5& 6 (β5)	57.10 ± 1.12	5.36 ± 0.05	61.81 ± 9.91	0,00 ± 0.00	54.39 ± 10.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 β4, 5 & 6					35.86 ± 2.97	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T0 β7, 8 & 9					52.41 ± 10.47	2.00 ± 2.82	0.00 ± 0.00	0.00 ± 0.00
T1 β7, 8 & 9					32.93 ± 1.96	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T0 β10, 11 & 12 (β11)	61.20 ± 0.11	5.71 ± 0.08	66.37 ± 8.22	0.00 ± 0.00	48.13 ± 7.71	1.49 ± 2.11	0.00 ± 0.00	0.00 ± 0.00
T1 β10, 11 & 12					35.51 ± 0.73	2.00 ± 2.82	0.00 ± 0.00	0.00 ± 0.00
T0 β13, 14 & 15					53.23 ± 4.80	4.86 ± 1.23	0.00 ± 0.00	0.00 ± 0.00
T1 β13, 14 & 15					33.25 ± 2.41	3.61 ± 0.89	0.00 ± 0.00	0.00 ± 0.00
T0 β16, 17 & 18 (β17)	55.42 ± 1.11	5.67 ± 0.36	49.54 ± 16.16	0.00 ± 0.00	42.42 ± 5.66	4.02 ± 1.46	0.00 ± 0.00	0.00 ± 0.00
T1 β16, 17 & 18					28.70 ± 2.88	1.93 ± 2.72	0.00 ± 0.00	0.00 ± 0.00
T0 χ1, 2 & 3 (χ2)	278.41 ± 11.14	7.62 ± 0.23	116.83 ± 12.92	0.00 ± 0.00	150.84 ± 16.36	6.12 ± 0.55	0.00 ± 0.00	0.00 ± 0.00
T1 χ1, 2 & 3					131.24 ± 1.58	6.13 ± 8.66	0.00 ± 0.00	0.00 ± 0.00
T0 δ1, 2 & 3 (δ2)	92.23 ± 2.02	4.49 ± 0.37	97.86 ± 8.60	0.00 ± 0.00	53.84 ± 6.82	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 δ1, 2 & 3					46.59 ± 7.47	1.72 ± 2.43	0.00 ± 0.00	0.00 ± 0.00

Table D3.4.4 Summary of Trihalomethane Results During the Summer and Fall Sampling at Pool III. Study of Pool Profiles and Time Profiles.

Sample Identification	Trihalomethane Concentration in µg/L							
	(Afternoon Sampling July 5, 1990)				Time Profile on December 5, 1990			
	CHCl3	CHCl2Br	CHClBr2	CHBr3	CHCl3	CHCl2Br	CHClBr2	CHBr3
T0 X1, 2, 3, 4 & 5 (2)	44.94 ± 0.30	3.87 ± 0.13	25.99 ± 1.11	0.00 ± 0.00	45.73 ± 1.80	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 X1, 2, 3, 4 & 5					42.59 ± 3.32	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T2 X1, 2, 3, 4 & 5					37.63 ± 0.38	2.67 ± 3.78	4.03 ± 5.69	0.00 ± 0.00
T0 Y1, 2, 3, 4 & 5 (2)	44.43 ± 0.04	4.08 ± 0.08	23.18 ± 3.07	0.00 ± 0.00	44.68 ± 2.23	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 Y1, 2, 3, 4 & 5					42.68 ± 0.78	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T2 Y1, 2, 3, 4 & 5					46.06 ± 3.37	1.59 ± 2.24	4.03 ± 5.69	0.00 ± 0.00
T0 Z1, 2, 3, 4 & 5 (1:5)	47.10 ± 1.07	4.09 ± 0.37	26.36 ± 0.86	0.00 ± 0.00	43.44 ± 1.45	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T1 Z1, 2, 3, 4 & 5 (3:4)	46.37 ± 2.21	4.91 ± 0.67	24.38 ± 1.26	0.00 ± 0.00	44.80 ± 0.22	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
T2 Z1, 2, 3, 4 & 5					45.83 ± 1.05	2.42 ± 0.11	0.00 ± 0.00	0.00 ± 0.00
T2 TAP WATER					50.14 ± 3.75	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

APPENDIX D4

Total Kjeldahl Nitrogen

APPENDIX D4.1

Standardization of Sulfuric Acid for TKN

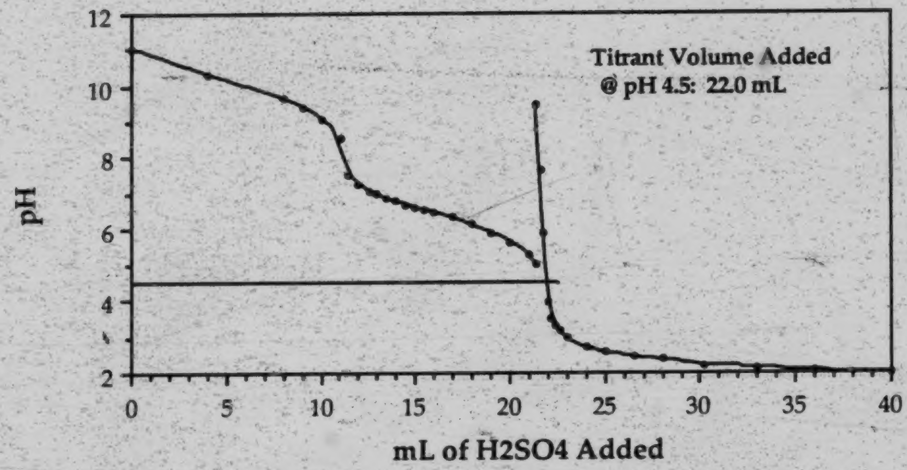


Figure D4.1a Standardization of Sulfuric Acid from June 11, 1990 by Potentiometric Titration of Sodium Bicarbonate.

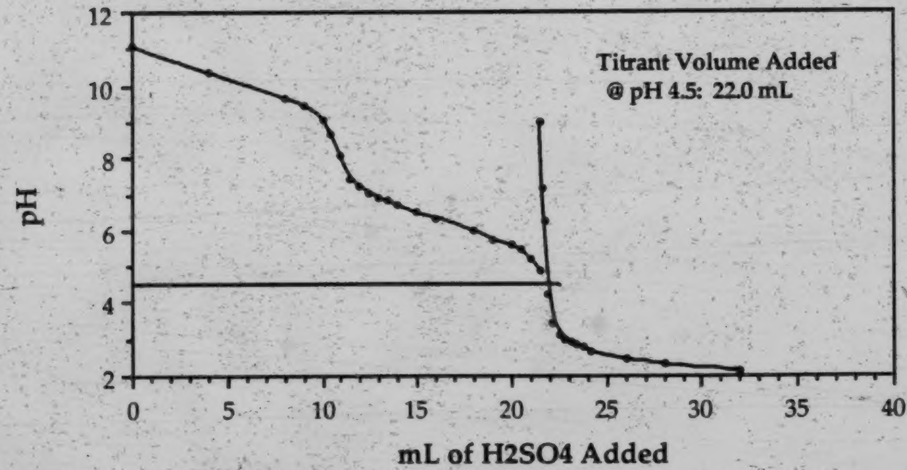


Figure D4.1b Standardization of Sulfuric Acid from June 11, 1990 by Potentiometric Titration of Sodium Bicarbonate.

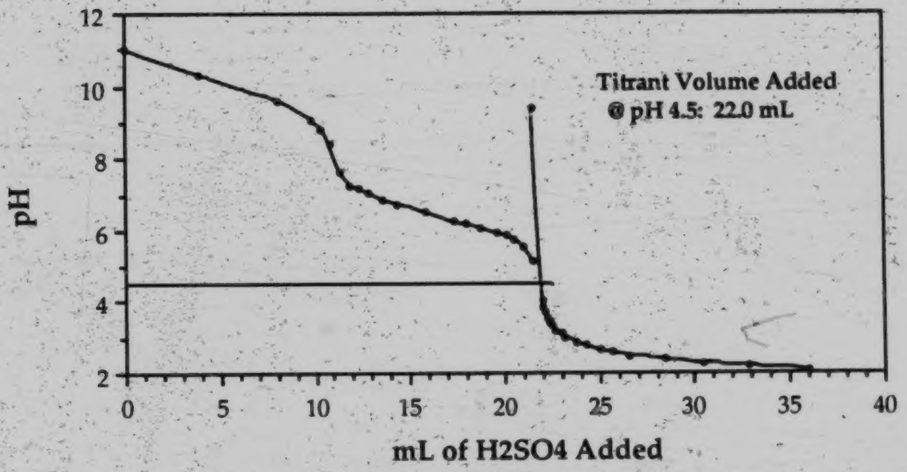


Figure D4.1c Standardization of Sulfuric Acid from June 11, 1990 by Potentiometric Titration of Sodium Bicarbonate.

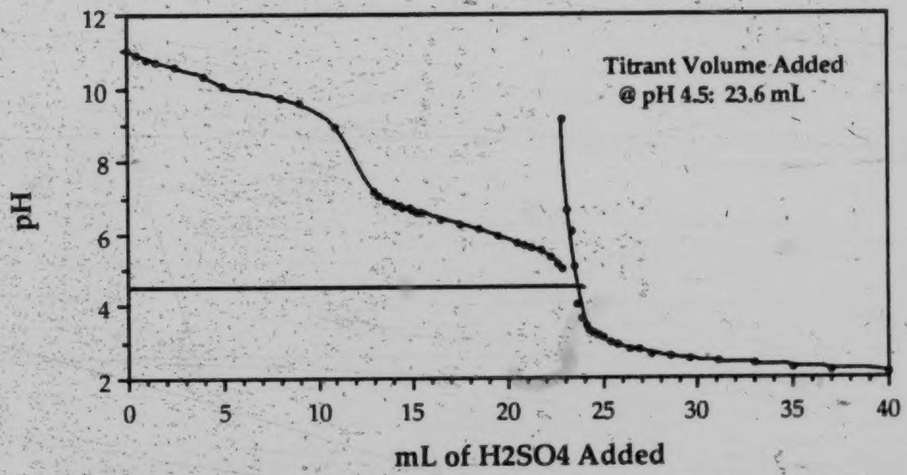


Figure D4.2a Standardization of Sulfuric Acid from December 9, 1990 by Potentiometric Titration of Sodium Bicarbonate.

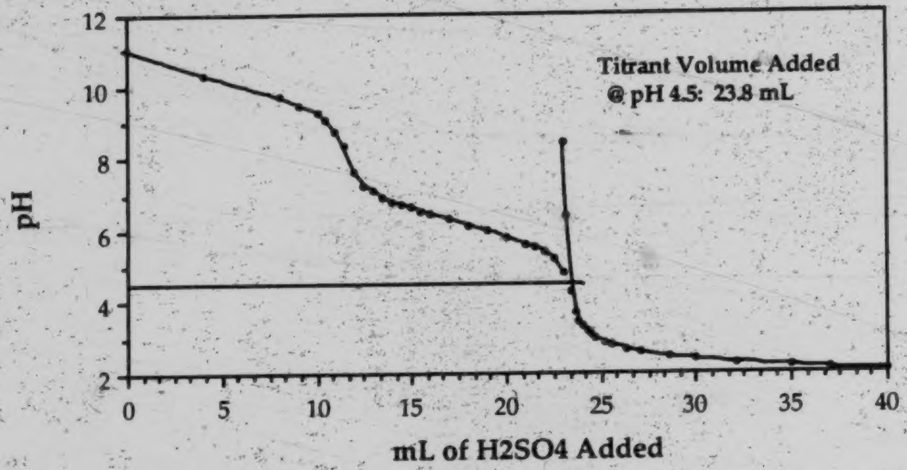


Figure D4.2b Standardization of Sulfuric Acid from December 9, 1990 by Potentiometric Titration of Sodium Bicarbonate.

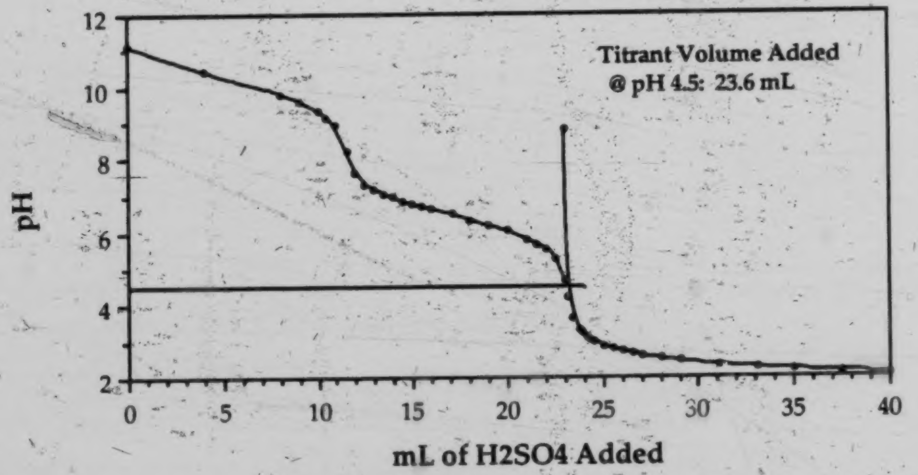


Figure D4.2c Standardization of Sulfuric Acid from December 9, 1990 by Potentiometric Titration of Sodium Bicarbonate.

APPENDIX D4.2

Total Kjeldahl Nitrogen Analysis Results

Table D4.2.1 Summary of Total Kjeldahl Nitrogen Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	**Kjeldahl Nitrogen Concentration in mg NH3-N/L**			
	July 26 1990	**July 30 1990**	**August 1 1990**	**August 6 1990**
A1	0.20 ± NA	0.18 ± 0.00	0.23 ± 0.04	0.16 ± 0.00
A2		0.17 ± 0.02	0.22 ± 0.01	0.14 ± 0.01
A3		0.14 ± 0.05	0.15 ± 0.03	0.10 ± 0.02
B1	0.16 ± NA	0.08 ± 0.06	0.08 ± 0.00	0.06 ± 0.04
B2		0.03 ± 0.03	0.06 ± 0.01	0.05 ± 0.02
B3		0.08 ± 0.04	0.05 ± 0.03	0.03 ± 0.00
C1	0.52 ± NA	0.46 ± 0.03	0.43 ± 0.03	0.35 ± 0.01
C2		0.41 ± 0.02	0.40 ± 0.02	0.38 ± 0.01
C3		0.44 ± 0.01	0.40 ± 0.50	0.33 ± 0.00
D1	0.53 ± NA	0.42 ± 0.01	0.42 ± 0.02	0.40 ± 0.01
D2		0.32 ± 0.08	0.38 ± 0.06	0.36 ± 0.03
D3		0.26 ± 0.23	0.38 ± NA	0.34 ± 0.04
E1	1.44 ± NA	0.38 ± 0.17	0.64 ± 0.16	1.20 ± 0.03
E2		0.52 ± NA	0.78 ± 0.07	1.22 ± 0.03
E3		0.47 ± 0.03	0.77 ± 0.04	1.19 ± 0.03

Table D4.2.2 Summary of Total Kjeldahl Nitrogen Results During the Fall Sampling at Pool I. Study of Time Profiles.

Sample Identification	Kjeldahl Nitrogen Concentration in mg of NH_3-N/L	
	Time Profile	
	October 9 1990	November 29 1990
T0 A1, 2 & 3	0.44 ± 0.02	0.58 ± 0.01
T1 A1, 2 & 3	0.44 ± 0.02	0.56 ± 0.01
T2 A1, 2 & 3	0.47 ± 0.00	0.58 ± 0.01
T0 B1, 2 & 3	0.03 ± 0.00	0.05 ± 0.02
T1 B1, 2 & 3	0.04 ± 0.01	0.11 ± 0.05
T2 B1, 2 & 3	0.03 ± 0.00	0.08 ± 0.01
T0 C1, 2 & 3	0.32 ± 0.00	0.64 ± 0.00
T1 C1, 2 & 3	0.30 ± 0.02	0.59 ± 0.02
T2 C1, 2 & 3	0.31 ± 0.03	0.59 ± 0.03
T0 D1, 2 & 3	0.33 ± 0.01	0.62 ± 0.02
T1 D1, 2 & 3	0.34 ± 0.03	0.63 ± 0.03
T2 D1, 2 & 3	0.34 ± 0.03	0.63 ± 0.06
T0 E1, 2 & 3	0.90 ± 0.01	0.62 ± 0.01
T1 E1, 2 & 3	0.89 ± 0.06	0.60 ± 0.00
T2 E1, 2 & 3	0.91 ± 0.05	0.61 ± 0.02

Table D4.2.3 Summary of Total Kjeldahl Nitrogen Results During the Summer and Fall Sampling at Pool II. Study of Pool Profiles and Time Profiles.

Sample Identification	**Kjeldahl Nitrogen Concentration in mg of NH3-N/L**	
	July 7 1990 (Afternoon)	**December 12 1990 Time Profile**
T0 α1, 2 & 3 (α2)	0.00 ± 0.00	0.44 ± 0.03
T1 α1, 2 & 3		0.44 ± 0.06
T0 β1, 2 & 3 (β2)	0.00 ± 0.00	0.47 ± 0.05
T1 β1, 2 & 3		0.43 ± 0.01
T0 β4,5 & 6 (β5)	0.00 ± 0.00	0.42 ± 0.05
T1 β4, 5 & 6		0.45 ± 0.02
T0 β7, 8 & 9 (β11)	0.00 ± 0.00	0.41 ± 0.00
T1 β7, 8 & 9		0.27 ± 0.08
T0 β10, 11 & 12		0.39 ± 0.02
T1 β10, 11 & 12		0.34 ± NA
T0 β13, 14 & 15		0.40 ± 0.01
T1 β13, 14 & 15		0.38 ± NA
T0 β16, 17 & 18 (17)	0.00 ± 0.00	0.41 ± 0.05
T1 β16, 17 & 18		0.43 ± NA
T0 χ1,2 & 3	0.15 ± 0.00	1.17 ± 0.02
T1 χ1,2 & 3		0.81 ± 0.09
T0 δ1,2 & 3	0.00 ± 0.00	0.83 ± 0.01
T1 δ1, 2 & 3		0.58 ± 0.09

Comments: July 7, 1990 analyses were performed on 100mL aliquot, while December 12 were performed on 500 mL aliquot.

Table D4.2.4 Summary of Total Kjeldahl Nitrogen Results During the Summer and Fall Sampling at Pool III. Study of Pool Profiles and Time Profiles.

Sample Identification	Kjeldahl Nitrogen Concentration in mg of NH3-N/L	
	July 5 1990 (Afternoon)	December 5 1990 Time Profile
T0 X1, 2, 3, 4 & 5 (2)	0.00 ± 0.00	0.21 ± 0.00
T1 X1, 2, 3, 4 & 5		0.23 ± 0.01
T2 X1, 2, 3, 4 & 5		0.22 ± 0.04
T0 Y1, 2, 3, 4 & 5 (2)	0.00 ± 0.00	0.23 ± 0.02
T1 Y1, 2, 3, 4 & 5		0.23 ± 0.01
T2 Y1, 2, 3, 4 & 5		0.20 ± 0.00
T0 Z1, 2, 3, 4 & 5 (1:5)	0.00 ± 0.00	0.23 ± 0.00
T1 Z1, 2, 3, 4 & 5 (3:4)	0.00 ± 0.00	0.21 ± 0.00
T2 Z1, 2, 3, 4 & 5		0.19 ± 0.01
T2 Tap-Feed line		0.21 ± NA

Comments: July 5, 1990 analyses were performed on 100 mL aliquot, while December 5 were performed on 500 mL aliquot

APPENDIX D5

Total Organic Carbon Analysis Results

Table D5.1 Summary of Total Organic Carbon Results During the Summer Sampling at Pool I. Study of Pool Profiles.

Sample Identification	Total Organic Carbon Concentration in mg of C/L			
	July 26 1990	July 30 1990	August 1 1990	August 6 1990
A1	5.199 ± 0.191	5.146 ± 0.195	5.078 ± 0.123	4.818 ± 0.155
A2		4.877 ± 0.156	4.733 ± 0.085	4.482 ± 0.115
A3		4.849 ± 0.177	4.670 ± 0.102	4.443 ± 0.098
B1	3.457 ± 0.286	3.023 ± 0.326	2.884 ± 0.052	2.702 ± 0.109
B2		2.987 ± 0.320	2.902 ± 0.168	2.799 ± 0.083
B3		2.886 ± 0.169	2.719 ± 0.056	2.742 ± 0.033
C1	10.03 ± 0.43	8.659 ± 0.113	8.318 ± 0.172	8.376 ± 0.239
C2		8.466 ± 0.116	8.204 ± 0.075	8.222 ± 0.072
C3		8.552 ± 0.300	8.098 ± 0.128	8.212 ± 0.133
D1	9.644 ± 0.086	8.407 ± 0.105	8.111 ± 0.130	8.330 ± 0.137
D2		8.321 ± 0.221	8.164 ± 0.122	8.220 ± 0.088
D3		8.404 ± 0.143	8.110 ± 0.420	8.240 ± 0.119
E1	24.20 ± 0.36	8.768 ± 0.050	13.33 ± 0.09	22.61 ± 0.08
E2		9.192 ± 0.667	14.71 ± 2.79	23.50 ± 2.00
E3		9.114 ± 0.541	13.41 ± 0.35	22.66 ± 0.20

Table D5.2 Summary of Total Organic Carbon Results During the Fall Sampling at Pool I. Study of Pool Profiles and Time Profiles

Sample ID	Total Organic Carbon Concentration in mg of C/L					
	October 9 1990			November 29 1990		
	Time 0	Time 1	Time 2	Time 0	Time 1	Time 2
A1	7.480 ± 0.562	7.051 ± 0.071	7.362 ± 0.272	9.70 ± 0.13	9.71 ± 0.11	10.14 ± 0.19
A2	7.354 ± 0.476	7.076 ± 0.049	7.100 ± 0.040	9.84 ± 0.09	10.22 ± 0.08	9.737 ± 0.074
A3	7.196 ± 0.528	7.139 ± 0.039	7.136 ± 0.105	9.670 ± 0.050	9.731 ± 0.097	9.98 ± 0.09
B1	2.033 ± 0.144	1.830 ± 0.116	1.905 ± 0.144	2.828 ± 0.121	3.030 ± 0.097	3.120 ± 0.120
B2	2.039 ± 0.037	1.961 ± 0.039	2.019 ± 0.062	2.946 ± 0.098	2.946 ± 0.033	3.211 ± 0.032
B3	2.199 ± 0.073	1.929 ± 0.018	2.037 ± 0.047	2.986 ± 0.082	2.968 ± 0.049	3.180 ± 0.069
C1	7.121 ± 0.355	6.936 ± 0.140	7.023 ± 0.221	14.19 ± 0.21	14.12 ± 0.19	14.03 ± 0.10
C2	7.467 ± 0.027	6.809 ± 0.043	6.769 ± 0.050	13.72 ± 0.05	13.85 ± 0.10	13.97 ± 0.17
C3	7.484 ± 0.766	6.683 ± 0.063	6.784 ± 0.041	13.74 ± 0.07	13.85 ± 0.09	14.15 ± 0.06
D1	6.826 ± 0.079	6.834 ± 0.131	7.445 ± 1.129	13.82 ± 0.06	13.90 ± 0.07	14.22 ± 0.04
D2	6.895 ± 0.055	6.799 ± 0.051	6.698 ± 0.118	14.21 ± 0.09	14.10 ± 0.09	14.77 ± 0.80
D3	6.915 ± 0.057	6.972 ± 0.051	6.903 ± 0.088	13.80 ± 0.60	13.95 ± 0.38	14.08 ± 0.14
E1	16.59 ± 0.03	16.67 ± 0.10	16.78 ± 0.07	9.344 ± 0.094	NA	10.34 ± 0.07
E2	17.19 ± 0.79	16.75 ± 0.14	16.49 ± 0.19	10.73 ± 0.92	10.58 ± 0.09	10,36 ± 0.08
E3	16.75 ± 0.35	16.77 ± 0.02	16.50 ± 0.11	9.553 ± 0.051	10.18 ± 0.08	10.38 ± 0.10

Comments: NA: Not Available, sample T1 E1 was lost.

Table D5.3 Summary of Total Organic Carbon Results During the Summer and Fall Sampling at Pool II. Study of Pool Profiles and Time Profiles.

Sample Identification	Kjeldahl Nitrogen Concentration in mg of NH3-N/L	
	July 7 1990 (Afternoon)	December 12 1990 Time Profile
T0 α1, 2 & 3 (α2) T1 α1, 2 & 3	0.00 ± 0.00	0.44 ± 0.03 0.44 ± 0.06
T0 β1, 2 & 3 (β2) T1 β1, 2 & 3	0.00 ± 0.00	0.47 ± 0.05 0.43 ± 0.01
T0 β4,5 & 6 (β5) T1 β4, 5 & 6	0.00 ± 0.00	0.42 ± 0.05 0.45 ± 0.02
T0 β7, 8 & 9 (β11) T1 β7, 8 & 9	0.00 ± 0.00	0.41 ± 0.00 0.27 ± 0.08
T0 β10, 11 & 12 T1 β10, 11 & 12		0.39 ± 0.02 0.34 ± NA
T0 β13, 14 & 15 T1 β13, 14 & 15		0.40 ± 0.01 0.38 ± NA
T0 β16, 17 & 18 (17) T1 β16, 17 & 18	0.00 ± 0.00	0.41 ± 0.05 0.43 ± NA
T0 χ1,2 & 3 T1 χ1,2 & 3	0.15 ± 0.00	1.17 ± 0.02 0.81 ± 0.09
T0 δ1,2 & 3 T1 δ1, 2 & 3	0.00 ± 0.00	0.83 ± 0.01 0.58 ± 0.09

Comments: July 7, 1990 analyses were performed on 100mL aliquot, while December 12 were performed on 500 mL aliquot.

Table D5.4 Summary of Total Organic Results During the Summer and Fall Sampling at Pool III. Study of Pool Profiles and Time Profiles.

Sample Identification	Total Organic Carbon Concentration in mg of C/L)			
	TC July 5, 1990 (Afternoon)	December 5,1990		
		Time 0	Time 1	Time 2
X1		6.212 ± 0.116	7.678 ± 0.209	6.017 ± 0.065
X2	5.194 ± 0.047	5.948 ± 0.078	6.026 ± 0.188	6.127 ± 0.036
X3		6.004 ± 0.190	6.104 ± 0.096	6.109 ± 0.072
X4		5.862 ± 0.088	5.988 ± 0.280	6.059 ± 0.095
X5		5.873 ± 0.078	6.036 ± 0.087	5.960 ± 0.409
Y1		6.576 ± 0.487	5.840 ± 0.217	6.015 ± 0.017
Y2	5.160 ± 0.035	6.164 ± 0.050	5.792 ± 0.276	5.993 ± 0.053
Y3		5.971 ± 0.033	5.716 ± 0.222	6.019 ± 0.029
Y4		5.974 ± 0.264	6.097 ± 0.207	6.051 ± 0.569
Y5		5.868 ± 0.175	6.068 ± 0.118	6.099 ± 0.058
Z1 (Z1:5)	5.297 ± 0.112	5.627 ± 0.169	6.112 ± 0.032	6.027 ± 0.037
Z2		5.794 ± 0.135	6.183 ± 0.061	6.127 ± 0.033
Z3 (Z3:4)	5.067 ± 0.049	6.092 ± 0.265	5.961 ± 0.059	6.171 ± 0.052
Z4		6.109 ± 0.036	5.978 ± 0.028	6.108 ± 0.071
Z5		6.097 ± 0.049	6.234 ± 0.059	6.173 ± 0.029
Tap-Feed Line				5.750 ± 0.476

Comments: Results for July 5, 1990 are Total Carbon readings not Total Organic Carbon results. (TOC = TC - IC)

APPENDIX D6

Large Volume Aqueous Extraction Analysis Results

Table D6.1 Large Volume Aqueous Neutral Extraction for Pool I-E.

Retention Time	Compound	Molecular Weight	Probability by MSD
4.405	unknown		
5.16	unknown		
9.744	1,2 dichloro 1-propene	109	45
10.215	3-chloro butanenitrile	103	40
12.619	benzaldehyde	106	91
13.513	butanedinitrile or iso	80	91
14.298	diethyl carbamic chloride	135	78
15.359	unknown		
15.821	pentanedinitrile	94	83
16.538	Bis-2-cyclohexene-1-yl	162	59
17.66	unknown		
18.751	benzeneacetonitrile or iso	117	94
19.734	tetrachloromethane	151	72
20.038	unknown		
25.147	unknown		
27.504	1-(3-ethylcyclobutyl)ethanone	126	43
27.622	unknown		
28.487	bis(1-methylethyl)hexanedioic acid	230	91
31.259	unknown		
31.475	N,N-diethyl-3-methyl benzamide	191	83
31.701	diethyl phthalate	222	94
32.38	... propanoic acid	286	72
39.931	... benzene dicarboxylic acid	278	95
41.766	unknown		
43.453	long chain alkane		
45.306	long chain alkane		
47.07	long chain alkane		
48.276	hexanedioic acid		40
48.766	long chain alkane		
50.405	long chain alkane		
50.53	3-nitro 1,2-benzene dicarboxylic acid		
51.479	long chain alkane	211	86
52.155	long chain alkane		
53.398	long chain alkane		
54.221	long chain alkane		

Table D6.2 Large Volume Aqueous Acid Extraction for Pool I-E.

Retention Time	Compound	Molecular Weight	Probability by MSD
4.426	unknown		
5.191	unknown		
10.174	3-chlorobutanenitrile	103	53
12.16	unknown		
12.643	benzaldehyde	106	94
13.567	butanedinitrile or iso	80	86
16.309	2,2,dichloro acetamide	126	47
16.421	pentanedinitrile or iso	94	53
17.71	unknown		
18.304	unknown		
18.817	benzeneacetonitrile	117	96
20.37	unknown		
22.359	ammonium salt of benzoic acid	139	72
24.274	phenyl propanedioic acid	180	86
25.006	nonanoic acid	158	70
27.081	decanoic acid	172	70
27.408	decanoic acid	172	86
28.555	bis (1-methylethyl)hexanedioic acid	230	83
29.545	undecanoic acid	186	89
29.931	unknown		
30.149	unknown		
30.872	unknown		
37.279	unknown		
31.784	diethyl phthalate	222	
32.38	dodecanoic acid	200	94
33.352	unknown		
33.471	unknown		
33.659	unknown		
33.857	unknown		
34.313	tridecanoic acid	214	94
35.653	unknown		
36.695	tetradecanoic acid	278	98
36.943	unknown		
37.638	unknown		
37.976	unknown		
38.561	pentadecanoic acid	242	96

Table D6.2 (Continued) Large Volume Aqueous Acid Extraction for Pool I-E.

Retention Time	Compound (Continued)	Molecular Weight	Probability by MSD
39.216	2,5 dihydro-2,5-methoxy furan	130	
40.655	hexadecanoic acid	256	93
41.548	long chain alkane		
41.776	unknown		
43.472	long chain alkane		
43.78	unknown		
44.435	octadecanoic acid		low
45.348	long chain alkane		
45.487	... benzene dicarboxylic acid	334	87
45.596	phthalate		
45.686	phthalate		
45.795	phthalate		
45.924	phthalate		
46.033	phthalate		
46.152	phthalate		
46.231	phthalate		
46.479	phthalate		
46.608	phthalate		
47.155	long chain alkane		
48.88	long chain alkane		
49.316	phthalate		
50.533	long chain alkane		
51.512	long chain alkane		
52.282	long chain alkane		
54.357	long chain alkane		

Table D6.3 Large Volume Aqueous Neutral Extraction for Pool II-χ.

Retention Time	Compound	Molecular Weight	Probability by MSD
9.684	unknown		
10.126	3-chlorobutanenitrile or iso	103	39
11.205	2-butoxy ethanal	118	53
11.951	5,5-dimethyl 2(5H) furanone	112	72
12.589	benzaldehyde	106	94
13.443	butanedinitrile	80	86
15.898	pentanedinitrile	94	83
17.44	2,2-dichloro 1,1,1-trifluoro ethane	151	72
18.569	benzeneacetonitrile	117	95
19.79	tetrachloromethane	151	72
25.134	unknown		
28.081	dimethyl phthalate	194	90
28.485	bis (1-methylethyl) hexanedioic acid	230	91
31.699	diethyl phthalate	222	91
32.397	... propanoic acid	286	72
39.942	... benzene dicarboxylic acid	276	97
41.764	unknown		
44.011	long chain alkane		
45.291	long chain alkane		
46.926	phthalate		
47.054	long chain alkane		
47.704	long chain alkane		
48.177	long chain alkane		
48.759	long chain alkane		
49.429	long chain alkane		
50.404	long chain alkane		
52.184	long chain alkane		
53.194	long chain alkane		
54.269	long chain alkane		

Table D6.4 Large Volume Aqueous Acid Extraction for Pool II-χ.

Retention Time	Compound	Molecular Weight	Probability by MSD
8.572	1,1,1,2-tetrachloro ethane	165	72
9.937	cyclohexanone	98	90
10.18	chlorocyclohexane	118	72
10.911	unknown		
11.441	2-butoxy ethanal	118	54
12.1	unknown		
12.587	benzaldehyde	106	64
12.827	butanedinitrile	80	72
15.618	unknown		
15.746	pentanedinitrile	94	83
16.592	Bi-2 cyclohexene-1-yl	162	50
17.3	1,2,2 trichloro-1,1-difluoro ethane	167	72
17.793	unknown		
18.58	benzeneacetonitrile	117	93
19.732	trichloro methane	151	64
20.136	2,2,2 trichloro acetamide	160	44
21.929	benzoic acid	122	92
22.285	hexanamine	101	43
24.433	unknown		
24.621	nonanoic acid	158	81
27.126	decanoic acid	172	68
28.103	dimethyl phthalate		90
28.507	bis (1-methylethyl) hexanedioic acid	230	86
29.415	undecanoic acid	186	72
29.53	unknown		
31.736	diethyl phthalate	222	95
32.033	dodecanoic acid	200	93
33.14	unknown		
33.29	unknown		
33.466	unknown		
34.[illegible]8	tridecanoic acid	214	95
35.52[illegible]	unknown		
36.521	tetradecanoic acid	228	96
37.36	unknown		
37.538	unknown		
37.716	unknown		

Table D6.4 (Continued) Large Volume Aqueous Acid Extraction for Pool II-χ.

Retention Time	Compound (Continued)	Molecular Weight	Probability by MSD
38.496	pentadecanoic acid	242	94
39.76	unknown		
39.948	phthalate		
40.609	hexadecanoic acid	256	93
41.539	unknown		
41.747	long chain alkane		
43.637	long chain alkane		
44.345	octadecanoic acid	282	47
45.302	long chain alkane		
47.059	long chain alkane		
48.262	dioctyl ester of hexanedioic acid	370	76
48.755	long chain alkane		
49.347	long chain alkane		
50.31	long chain alkane		
50.529	phthalate		
52.142	long chain alkane		
53.46	long chain alkane		
54.198	long chain alkane		

Table D6.5 Large Volume Aqueous Neutral Extraction for Pool III section Y.

Retention Time	Compound	Molecular Weight	Probability by MSD
4.405	unknown		
5.151	unknown		
9.71	unknown		
12.618	benzaldehyde	106	94
14.122	methyl propanedinitrile or butanedinitrile	80	91
16.483	pentanedinitrile	94	83
17.576	1,2,2 trichloro-1,1-difluoro ethane	167	53
18.778	benzeneacetonitrile	117	96
19.772	tetrachloromethane	151	64
31.716	diethyl phthalate	222	93
35.15	6-chloro-1,3,5-triazine-2,4-diamine	201	94
39.944	... benzene dicarboxylic acid	278	97
40.417	long chain alkane		
41.748	unknown		
45.285	long chain alkane		
45.453	long chain alkane		
46.664	unknown		
46.92	benzyl butyl phthalate		
47.039	long chain alkane		
48.034	long chain alkane		
48.724	long chain alkane		
49.236	long chain alkane		
49.757	phthalate		
50.743	phthalate		
52.14	long chain alkane		

Table D6.6 Large Volume Aqueous Acid Extraction for Pool III section Y.

Retention Time	Compound	Molecular Weight	Probability by MSD
4.384	unknown		
5.147	3-chlorobutanenitrile	106	38
9.688	unknown		
10.188	unknown		
11.788	unknown		
12.543	benzaldehyde	106	91
13.299	butanedinitrile	80	64
16.253	pentanedinitrile	94	64
17.355	1,2,2-trichloro-1,1-difluoro ethane	167	72
18.663	benzeneacetonitrile	117	94
20.464	2,2,2-trichloroacetamide	160	80
22.38	ammonium salt of benzoic acid	139	64
24.107	phenyl propanedioic acid	180	72
24.936	... oic acid		
27.045	decanoic acid	172	60
29.553	undecanoic acid	186	94
31.726	diethyl phthalate	222	94
32.231	dodecanoic acid	200	93
33.246	unknown		
33.566	unknown		
34.258	tridecanoic acid	214	95
35.375	unknown		
36.601	tetradecanoic acid	228	98
37.382	unknown		
37.58	unknown		
37.738	unknown		
38.538	pentadecanoic acid	242	83
40.661	hexadecanoic acid	256	93
41.738	unknown		
43.344	unknown		
43.669	unknown		
44.32	octadecanoic acid	284	64
45.295	unknown		
46.633	unknown		
46.909	benzyl butyl phthalate		87

Table D6.6 (Continued) Large Volume Aqueous Acid Extraction for Pool III section Y.

Retention Time	Compound	Molecular Weight	Probability by MSD
47.017	long chain alkane		
48.245	dioctyl ester of hexanedioic acid	370	81
48.707	long chain alkane		
50.69	phthalate		
52.111	long chain alkane		
54.186	long chain alkane		

Table D6.7 Large Volume of Extraction Solvent Concentrated for Blank Study.

Retention Time	Compound BLANK	Molecular Weight	Probability by MSD
12.509	unknown		
48.444	dioctyl ester of hexanedioic acid		
50.722	phthalate		

APPENDIX D7

Air Phase Analysis

APPENDIX D7.1

Hydrazones Calibration Curves

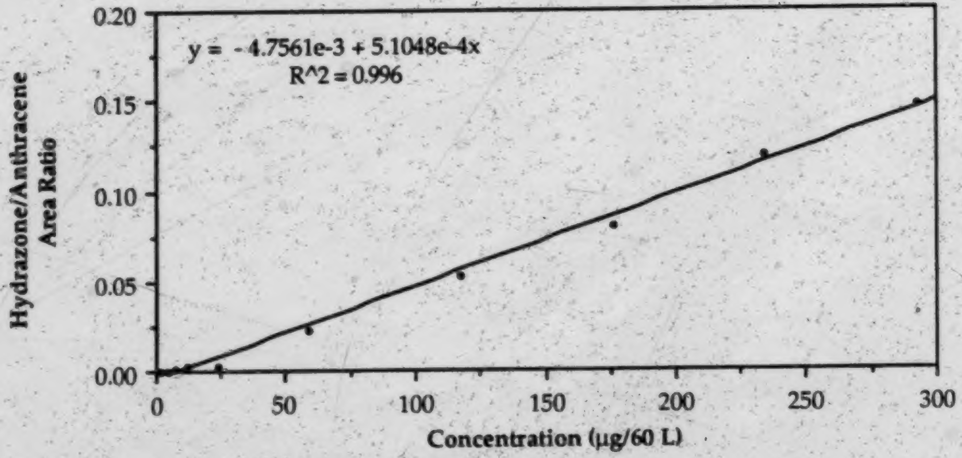


Figure D7.1.1 Formaldehyde Calibration Curve as the 2,4-Dinitrophenylhydrazone, October 24, 1990.

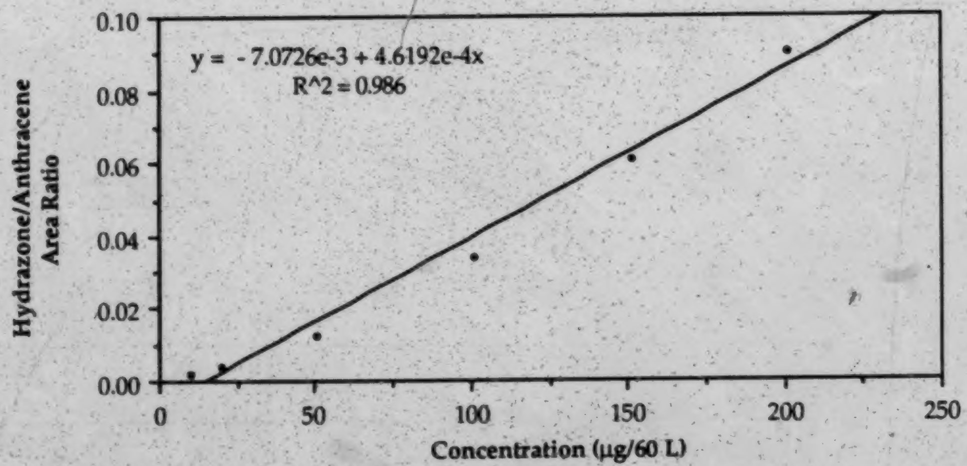


Figure D7.1.2 Acetaldehyde Calibration Curve as the 2,4-Dinitrophenylhydrazone, October 25, 1990.

APPENDIX D7.2

Recovery Trials

Table D7.2.1 Recovery Trial with Acetaldehyde Using Open System.

Concentration Spiked µg/m³	Concentration Recovered µg/m³	Recovery Efficiency %
0	44.5	-
113.8	147.8	130
227.7	203.0	89
569.2	282.6	50
569.2	216.1	38
1138.3	265.5	23

Table D7.2.2 Recovery Trial with Acetaldehyde Using Closed System.

Concentration Spiked µg/m³	Concentration Recovered µg/m³	Recovery Efficiency %
0	7.9	-
91.8	34.7	38
499.0	100.8	20

APPENDIX D7.3

Controlled Water Basin Trials

Table D7.3.1 Controlled Water Basin Trial with Formaldehyde and Acetaldehyde in the Aqueous Phase.

Aqueous Concentration		Overlying Atmosphere Concentration		Collection Efficiency	
Formaldehyde mg/L	Acetaldehyde mg/L	Formaldehyde μg/m³	Acetaldehyde μg/m³	Formaldehyde %	Acetaldehyde %
6.25	9.55	82.55	743.1	3.92	0.09

Note: Maximum expectable concentrations as calculated with H* under ideal conditions: Formaldehyde 2104.4 μg/m³, and Acetaldehyde 837090 μg/m³.

Table D7.3.2 Controlled Water Basin Trial with Formaldehyde and Acetaldehyde in the Aqueous Phase.

Aqueous Concentration		Overlying Atmosphere Concentration		Average Collection Efficiency	
Formaldehyde mg/L	Acetaldehyde mg/L	Formaldehyde μg/m³	Acetaldehyde μg/m³	Formaldehyde %	Acetaldehyde %
14.06	11.42	93.3	729.5	1.97	0.07

Note: Maximum expectable concentrations as calculated with H* under ideal conditions: Formaldehyde 4732.5 μg/m³, and Acetaldehyde 1001500 μg/m³.

APPENDIX D8

Physical Parameters Measured

Table D8.1 Physical Parameters and Sampling Information for Pool I on October 9, 1990.

Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group,...
A	10:42	T0-A1 T0-A2 T0-A3	26.0	7.9		4 female adults 4 male adults Aged 25-35 y
B	11:02	T0-B1 T0-B2 T0-B3	28.5	8.0		0
C	11:20	T0-CI T0-C2 T0-C3	27.0	7.8		0
D	11:31	T0-D1 T0-D2 T0-D3	28.0	7.8		2 adults
E	11:40	T0-E1 T0-E2 T0-E3	35.5	8.0		2 adults

Table D8.1 (Continued) Physical Parameters and Sampling Information for Pool I on October 9, 1990.

Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group,...
A	13:40	T1-A1 T1-A2 T1-A3	26.5	7.9		7 adults
B	14:00	T1-B1 T1-B2 T1-B3	29.5	8.0		
C	14:20	T1-CI T1-C2 T1-C3	28.0	7.7		
D	14:26	T1-D1 T1-D2 T1-D3	28.0	7.8		
E	14:39	T1-E1 T1-E2 T1-E3	35.0	8.1		

Table D8.1 (Continued) Physical Parameters and Sampling Information for Pool I on October 9, 1990.

Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group,...
A	17:28	T2-A1 T2-A2 T2-A3	26.0	7.9		36 swimmers (teenage: male and female)
B	16:55	T2-B1 T2-B2 T2-B3	29.0	8.1		15 swimmers (synchronized swimming)
C	17:11	T2-C1 T2-C2 T0-C2	28.0	7.7		20 people
D	16:33	T2-D1 T2-D2 T2-D3	28.0	7.7		6 people
E	16:42	T2-E1 T2-E2 T2-E3	35.5	8.2		2 people

Table D8.2 Physical Parameters and Sampling Information for Pool I on November 29, 1990.

Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group,...
A	9:25	T0-A1 T0-A2 T0-A3	27.0	8.1	1120 1120 1110	3 female adults 11 male adults Aged 20-50 y
B	9:50	T0-B1 T0-B2 T0-B3	29.0	7.6	300 300 260	Ø
C	10:05	T0-CI T0-C2 T0-C3	28.0	7.6	1640 1660 1670	16 female adults Aged 50-65 y
D	10:25	T0-D1 T0-D2 T0-D3	27.0	7.6	1660 1670 1660	1 male adult (50 y) 2 female adults (30-40 y) 5 male boys, 2 female girls
E	10:40	T0-E1 T0-E2 T0-E3	35.0	7.7	1200 1160 1200	6 female adults 5 children (< 3 y)

Table D8.2 (Continued) Physical Parameters and Sampling Information for Pool I on November 29, 1990.

Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group,...
A	13:35	T1-A1 T1-A2 T1-A3	27.5	7.7	1080 1060 1060	1 female adult 3 male adults Aged 50-65 y
B	13:21	T1-B1 T1-B2 T1-B3	29.0	7.7	870 870 880	3 male adults (25-35 y)
C	12:40	T1-CI T1-C2 T1-C3	28.0	7.6	1560 1560 1560	25 kids (10-12 y)
D	13:00	T1-D1 T1-D2 T1-D3	27.5	7.6	1550 1550 1560	25 kids (10-12 y)
E	13:55	T1-E1 T1-E2 T1-E3	35.5	7.6	1240 1240 1230	2 male adults 1 female adults 1 boy (4 y)

Table D8.2 (Continued) Physical Parameters and Sampling Information for Pool I on November 29, 1990.

Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group,...
A	15:30	T2-A1	27.5	7.9	1040	5 female adults
		T2-A2			1040	2 male adults
		T2-A3			1040	
B	15:39	T2-B1	28.5	7.9	870	3 female adults (25-35 y)
		T2-B2			870	
		T2-B3			870	
C	16:10	T2-C1	28.0	7.6	1550	Ø
		T2-C2			1550	
		T0-C2			1550	
D	15:58	T2-D1	28.5	7.7	1560	1 child
		T2-D2			1560	3 male adults
		T2-D3			1560	3 women adults
E	16:22	T2-E1	35.5	7.7	1170	4 male adults
		T2-E2			1150	2 female adults
		T2-E3			1140	3 kids (2 y)

Table D8.3 Physical Parameters and Sampling Information for Pool II on December 2, 1990.

Pool or Part of Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@°C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group, ...
α	9:43	T0–α1	28.0	7.5	1380	
		T0–α2			1360	
		T0–α3			1350	
β deep end	9:56	T0–β1	28.0	7.5	1540	
		T0–β2			1540	
		T0–β3			1540	
β 3" Pool	10:11	T0–β4	28.0	7.5	1530	1 male adult (30 y),
		T0–β5			1540	1 male child (3 y)
		T0–β6			1530	
β Centre-Left	10:20	T0–β7	28.0	7.6	1540	
		T0–β8			1560	
		T0–β9			1550	
β Centre-Centre	10:44	T0–β10	28.0	7.4	1560	
		T0–β11			1560	
		T0–β12			1550	
β Centre-Right	11:00	T0–β13	28.0	7.5	1560	
		T0–β14			1570	
		T0–β15			1570	
β Kiddy's Pool	10:35	T0–β16	28.0	7.6	1560	1 female adult,
		T0–β17			1590	1 female child
		T0–β18			1560	
χ	11:13	T0–χ1	38.0	7.4	2320	
		T0–χ2			2360	0
		T0–χ3			2350	
δ	11:21	T0–δ1	41.5	7.2	2390	1 male adult,
		T0–δ2			2390	1 female
		T0–δ3			2400	

Table D8.3 (Continued) Physical Parameters and Sampling Information for Pool II on December 2, 1990.

Pool or Part of Pool Sampled	Time Sampled	Sample Identification	Temperature °C (2 Readings)	pH (@°C)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age group, ...
α	13:26	T1–α1 T1–α2 T1–α3	27.5	7.6	1310 1320 1320	10, 10 year old (3 females and 7 males)
β deep end	13:36	T1–β1 T1–β2 T1–β3		7.6	1460 1510 1510	7 males (boys-10 y)
β 3" Pool	13:47	T1–β4 T1–β5 T1–β6	28.0	7.5	1520 1480 1520	3 females (girls-10 y)
β Centre-Left		T1–β7 T1–β8 T1–β9		NA	1490 1510 1500	
β Centre-Centre	14:40	T1–β10 T1–β11 T1–β12		NA	1530 1530 1530	
β Centre-Right	14:25	T1–β13 T1–β14 T1–β15	28.5	NA	1530 1520 1520	
β Kiddy's Pool	14:11	T1–β16 T1–β17 T1–β18		NA	1520 1550 1540	2 females (girls-10 y), 2 males (boys-10 y) 2 adults
χ	14:55	T1–χ1 T1–χ2 T1–χ3	28.0	NA	2350 2390 2350	0
δ	14:55	T1–δ1 T1–δ2 T1–δ3	41.0	NA	2410 2430 2420	1 female adult, 1 female kid

Comments: NA: not available, pH pen fell in the pool

Table D8.4 Physical Parameters and Sampling Information for Pool III on December 5, 1990.

Part of Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@ C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age Group, ...
Shallow End X	9:33	T0-X1	28.0	7.1	1700	Ø people
		T0-X2			1700	
		T0-X3			1690	
		T0-X4			1690	
		T0-X5			1700	
Middle Y	9:48	T0-Y1	28.0	7.1	1710	2 male adults
		T0-Y2			1710	
		T0-Y3			1710	
		T0-Y4			1700	
		T0-Y5			1710	
Deep End Z	10:07	T0-Z1	28.0	7.1	1690	1 male adult (Kayakist)
		T0-Z2			1710	
		T0-Z3			1710	
		T0-Z4			1710	
		T0-Z5			1710	

Table D8.4 (Continued) Physical Parameters and Sampling Information for Pool III on December 5, 1990.

Part of Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@ C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age Group, ...
Shallow End X	12:55	T1-X1	27.5	7.9	1660	6 male adults (20-25 y) "playing ball"
		T1-X2			1710	
		T1-X3			1710	
		T1-X4			1710	
		T1-X5			1710	
Middle Y	1:15	T1-Y1	27.5	7.9	1710	1 female adult 1 male adult
		T1-Y2			1720	
		T1-Y3			1720	
		T1-Y4			1720	
		T1-Y5			1720	
Deep End Z	1:30	T1-Z1	28.0	7.9	1720	Ø
		T1-Z2			1730	
		T1-Z3			1720	
		T1-Z4			1730	
		T1-Z5			1710	

Table D8.4 (Continued) Physical Parameters and Sampling Information for Pool III on December 5, 1990.

Part of Pool Sampled	Time Sampled	Sample Identification	Temperature °C (per section)	pH (@ C) (per section)	Conductivity µMHOS (@ °C)	REMARKS: # of People, Sex, Age Group, ...
Shallow End X	15:14	T2-X1 T2-X2 T2-X3 T2-X4 T2-X5	28.0	7.8	1680 1680 1670 1680 1680	0
Middle Y	15:22	T2-Y1 T2-Y2 T2-Y3 T2-Y4 T2-Y5	28.0	7.9	1700 1700 1710 1700 1710	1 female adult
Deep End Z	15:40	T2-Z1 T2-Z2 T2-Z3 T2-Z4 T2-Z5	27.5	7.9	1720 1730 1730 1730 1730	0
Tap Water	Afternoon	Feed Line	NA	NA	1750	Not applicable

Comments: NA: Not Available.

APPENDIX E

Microbial Analysis Results

APPENDIX E1

Aqueous Phase Microbial Results

Table E1.1 Microbial Results for the Water Phase at Pool I on July 26, 1990.

Sample Location	Heterotrophic Plate Count	Total Coliforms	Faecal Coliforms	Presumptive *Klebsiella*	Presumptive *P. aeruginosa*	Faecal Streptococcus
	cfu/mL	cfu/100 mL	cfu/100 mL	cfu 100 mL	cfu/100 mL	cfu/100 mL
A1	Confluent Growth	14	<1	26	Confluent Growth	50
A2	Confluent Growth	<1	<1	<1	<1	2
B2	Confluent Growth	10	<1	<1	<1	2
C2	Confluent Growth	<1	<1	<1	<1	<1
B2	Confluent Growth	<1	<1	<1	<1	6
E2	Confluent Growth	2	<1	<1	<1	8
E3	Confluent Growth	<1	2	<1	Confluent Growth	18

Table E1.2 Microbial Results for the Water Phase at Pool I on July 30, 1990.

Sample Location	Heterotrophic count	Total Coliforms	Faecal Coliforms	Presumptive *Klebsiella*	Presumptive *P. aeruginosa*	Faecal Streptococcus
	cfu/mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL
A1	26	64	1	<1	6	48
A2	20	2	<1	2	<1	2
A3	36	66	2	<1	<1	36
B1	4	26	<1	<1	<1	6
B2	20	4	<1	<1	<1	2
B3	16	32	2	<1	<1	4
C1	30	24	<1	<1	2	<1
C2	78	2	<1	4	<1	2
C3	23	20	<1	4	<1	2
D1	65	20	<1	<1	<1	4
D2	56	<1	<1	12	<1	<1
D3	254	28	<1	2	<1	4
E1	11 (2 molds)	20	2	<1	<1	<1
E2	14 (1 mold)	6	6	<1	<1	<1
E3	9	22	2	<1	<1	<1

Table E1.3 Microbial Results for the Water Phase at Pool I on August 1, 1990.

Sample Location	**Heterotrophic Plate Counts**	**Total Coliforms**	**Faecal Coliforms**	**Presumptive *Klebsiella***	**Presumptive *P. aeruginosa***	**Faecal Streptococcus**
	cfu/mL	**cfu/100 mL**	**cfu/100 mL**	**cfu/100 mL**	**cfu/100 mL**	**cfu/100 mL**
A1	1	2	<1	12	<1	<1
A2	1	<1	<1	<1	<1	<1
A3	6	<1	<1	14	<1	<1
B1	4	<1	<1	<1	<1	<1
B2	2	<1	<1	<1	<1	<1
B3	1	<1	<1	4	<1	<1
C1	2	<1	<1	2	<1	<1
C2	5	<1	<1	2	2	<1
C3	3	<1	<1	8	<1	<1
D1	9	<1	<1	<1	<1	<1
D2	26	<1	<1	10	<1	2
E1	2	6	<1	20	4	10
E2	10	76	2	28	4	42
E3	5	34	<1	22	4	6

Table E1.4 Microbial Results for the Water Phase at Pool I on August 6, 1990.

Sample Location	Heterotrophic Plate Counts	Total Coliforms	Faecal Coliforms	Presumptive *Klebsiella*	Presumptive *P. aeruginosa*	Faecal Streptococcus
	cfu/mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL
A1	8	2	<1	<1	2	22
A2	27	2	<1	2	<1	8
A3	4	<1	<1	<1	<1	<1
B1	10	<1	<1	<1	<1	<1
B2	2	<1	<1	<1	<1	2
C1	8	<1	<1	<1	<1	2
C2	45	<1	<1	2	<1	<1
C3	6	<1	<1	<1	<1	<1
D1	12	<1	<1	<1	<1	2
D2	3	<1	<1	<1	<1	<1
D3	3	<1	<1	<1	<1	2
E1	24	26	4	2	<1	<1
E2	3	2	2	<1	<1	<1
E3	21	2	<1	<1	<1	<1

Table E1.5 Microbial Results for the Water Phase at Pool I on November 29, 1990 at Time 0.

Sample Location at Time 0	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
A1	2	1	<1	8	<1	<1
A2	<1	<1	<1	1	<1	<1
A3	1	3	<1	1	<1	1
B1	2	101	2	<1	<1	1
B2	8	7	<1	<1	<1	<1
B3	7	4	<1	3	<1	2
C1	1	145	<1	<1	<1	3
C2	2	144	<1	<1	<1	<1
C3	5	<1	<1	<1	<1	<1
D1	15	Confluent Grotwh	<1	<1	<1	12
D2	7	11	<1	<1	<1	<1
D3	5	<1	<1	<1	<1	4
E1	3	2	<1	<1	<1	<1
E2	18	21	12	9	<1	<1
E3	3	118	<1	<1	<1	2

Table E1.6 Microbial Results for the Water Phase at Pool I on November 29, 1990 at Time 1.

Sample Location at Time 1	Heterotrophic Plate Counts	Total Coliforms	Faecal Coliforms	Presumptive *Klebsiella*	Presumptive *P. aeruginosa*	Faecal Streptococcus
	cfu/mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL	cfu/100 mL
A1	1	<1	<1	<1	<1	<1
A2	<1	<1	<1	<1	<1	<1
A3	3	<1	<1	<1	<1	<1
B1	1	4	<1	2	<1	<1
B2	2	11	<1	<1	<1	<1
B3	10	110	<1	2	<1	<1
C1	3	2	<1	<1	<1	<1
C2	3	2	<1	<1	<1	<1
C3	15	2	<1	<1	<1	<1
D1	42	2	<1	<1	<1	<1
D2	49	162	<1	2	<1	<1
D3	29	78	<1	<1	<1	<1
E1	1	4	<1	<1	<1	<1
E2	1	<1	<1	<1	<1	<1
E3	<1	3	<1	<1	<1	<1

Table E1.7 Microbial Results for the Water Phase at Pool I on November 29, 1990 at Time 2.

Sample Location at Time 2	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
A1	13	<1	<1	<1	<1	1
A2	Confluent Growth	4	Confluent Growth	<1	<1	1
A3	2	<1	<1	<1	<1	<1
B1	2	<1	<1	<1	<1	<1
B2	73	<1	<1	<1	<1	<1
B3	16	26	1	<1	<1	<1
C1	Confluent Growth	19	<1	<1	<1	<1
C2	Confluent Growth	1	7	4	<1	<1
C3	Confluent Growth	3	2	<1	<1	<1
D1	Confluent Growth	<1	1	<1	<1	2
D2	Confluent Growth	1	<1	2	<1	<1
D3	94	20	13	<1	<1	<1
E1	22	1	<1	<1	<1	<1
E2	30	<1	<1	<1	<1	<1
E3	Confluent Growth	42	32	<1	<1	<1

Table E1.8 Microbial Results for the Water Phase at Pool II on December 12, 1990 at Time 0.

Sample Location at Time 0	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
α1,2 & 3	5	<1	<1	<1	<1	<1
β1,2 & 3	20	<1	<1	<1	Confluent Growth	<1
β4,5 & 6	Confluemt Growth	<1	<1	<1	<1	<1
β7,8 & 9	36	<1	<1	<1	<1	<1
β10, 11 & 12	31	<1 *	<1	<1	<1	<1
β13, 14 & 15	Confluent Growth	<1	<1	<1	<1	<1
β16, 17 & 18	118	<1	<1	<1	<1	<1
χ1, 2 & 3.	17	<1	<1	<1	<1	5
δ1, 2 & 3	22	191	<1	<1	<1	143

*Insects (beetles)

Table E1.9 Microbial Results for the Water Phase at Pool II on December 12, 1990 at Time 1.

Sample Location at Time 1	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
α1,2 & 3	19	5	<1	<1	<1	4
β1,2 & 3	8	17	<1	<1	<1	6
β4,5 & 6	21	20	<1	<1	<1	11
β7,8 & 9	72	52	<1	<1	<1	28
β10, 11 & 12	26	14	<1	<1	<1	16
β13, 14 & 15	73	44	<1	<1	<1	22
β16, 17 & 18	35	10	<1	<1	<1	12
χ1, 2 & 3	27	<1	<1	<1	<1	<1
δ1, 2 & 3	22	16	<1	<1	<1	4

Table E1.10 Microbial Results for the Water Phase at Pool III on December 5, 1990 at Time 0.

Sample Location at Time 0	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
X1	79	1	<1	8	<1	<1
X2	Confluent Growth	<1	<1	1	<1	<1
X3	<1	3	<1	1	<1	1
X4	Confluent Growth	101	2	<1	<1	1
X5	2	7	<1	<1	<1	<1
Y1	Confluent Growth	4	<1	3	<1	2
Y2	Confluent Growth	145	<1	<1	<1	3
Y3	Confluent Growth	144	<1	<1	<1	<1
Y4	Confluent Growth	<1	<1	<1	<1	<1
Y5	Confluent Growth	Confluent Grotwh	<1	<1	<1	12
Z1	Confluent Growth	11	<1	<1	<1	<1
Z2	86	<1	<1	<1	<1	4
Z3	Confluent Growth	2	<1	<1	<1	<1
Z4	Confluent Growth	21	12	9	<1	<1
Z5	53	118	<1	<1	<1	2

Table E1.11 Microbial Results for the Water Phase at Pool III on December 5, 1990 at Time 1.

Sample Location at Time 1	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
X1	Confluent Growth	<1	<1	<1	1	20
X2	Confluent Growth	<1	<1	6	<1	3
X3	82	<1	<1	<1	<1	1
X4	Confluent Growth	14	<1	14	<1	38
X5	11	<1	<1	1	<1	<1
Y1	121	2	<1	<1	<1	72
Y2	8	<1	<1	3	<1	222
Y3	43	1	<1	<1	<1	24
Y4	94	<1	<1	<1	<1	32
Y5	150	6	<1	<1	<1	100
Z1	17	2	<1	<1	<1	10
Z2	74	<1	<1	<1	<1	4
Z3	52	<1	<1	14	<1	19
Z4	10	3	<1	<1	<1	118
Z5	Confluent Growth	<1	<1	<1	<1	38

Table E1.12 Microbial Results for the Water Phase at Pool III on December 5, 1990 at Time 2.

Sample Location at Time 2	Heterotrophic Plate Counts cfu/mL	Total Coliforms cfu/100 mL	Faecal Coliforms cfu/100 mL	Presumptive *Klebsiella* cfu/100 mL	Presumptive *P. aeruginosa* cfu/100 mL	Faecal Streptococcus cfu/100 mL
X1	Confluent Growth	34	<1	9	<1	25
X2	Confluent Growth	4	<1	Confluent Growth	3	278
X3	Confluent Growth	53	<1	<1	5	138
X4	Confluent Growth	<1	<1	<1	<1	Confluent Growth
X5	79	156	<1	<1	22	26
Y1	Confluent Growth	<1	<1	<1	<1	66
Y2	Confluent Growth	<1	<1			7
Y3	Confluent Growth	2	<1	<1	<1	52
Y4	Confluent Growth	<1	<1	<1	<1	109
Y5	Confluent Growth	<1	<1	<1	<1	32
Z1	Confluent Growth	<1	<1	9	<1	2
Z2	Confluent Growth	4	2	<1	<1	<1
Z3	19	<1	<1	<1	<1	10
Z4	73	<1	<1	<1	<1	<1
Z5	Confluent Growth	<1	<1	<1	1	117
Water from Feed Line	<1	<1	<1	<1	<1	3

APPENDIX E2

Air Phase Aerosol Results

Table E2.1 Aerosol Sampling Codes for Pool I.

Pool I

I-1	A1 pool , (Nutrient agar)
I-2	A1 pool, (Rose Bengal agar)
I-3	A3 pool, (Nutrient agar)
I-4	A3 pool, (Rose Bengal agar)
I-5	C3 pool, (Nutrient agar)
I-6	C3 pool, ladies aquasize class (Rose Bengal agar)
I-7	C2 pool, ladies aquasize class (Rose Bengal agar)
I-8	C2 pool, ladies aquasize class (Nutrient agar)
I-9	C pool, from pool end, middle (Nutrient agar)
I-10	D pool, from bulkhead (Rose Bengal agar)
I-11	D pool, from bulkhead (Nutrient agar)
I-12	E pool, Middle of ledge, (Nutrient agar)
I-13	E pool, Middle of ledge (Rose Bengal)
I-14	C pool, poolside, middle (Nutrient agar)
I-15	C pool, poolside, middle (Rose Bengal)
I-16	E pool, Middle of ledge (Rose Bengal)
I-17	A pool, poolside, middle, during swim practice (Rose Bengal)
I-18	A pool, poolside, middle, during swim practice (Nutrient agar)

Table E2.2 Microbial Results for the Air Phase at Pool I on November 29, 1990.

Sample Code	Time of Day	Bather Load	Bacteria	Fungi	Actinomycete	Yeasts
			cfu/m^3	cfu/m^3	cfu/m^3	cfu/m^3
I-1 (NA)	09:20		338	0		0
I-2 (RB)	09:30		0	9	0	9
I-3 (NA)	09:45		303	0	0	0
I-4 (RB)	09:55		0	0	0	0
I-5 (NA)	10:06	16	188	0	0	0
I-6 (RB)	10:15	16	0	13	0	0
I-7 (RB)	10:25	16	0	9	0	0
I-8 (NA)	10:35	17	138	9	0	0
I-9 (NA)	12:30	4	747	28	0	0
I-10 (RB)	12:50	29	0	0	0	13
I-11 (NA)	13:00	29	66	6	0	0
I-12 (NA)	13:10	12	241	0	0	0
I-13 (RB)	13:20	12	0	9	0	0
I-14 (NA)	15:35	16	103	6	0	0
I-15 (RB)	15:50	16	0	0	0	0
I-16 (RB)	16:00	8	0	0	0	0
I-17 (RB)	16:15	32	0	0	0	0
I-18 (NA)	16:25	32	41	9	0	0

RB: Rose Bengal agar
NA: Nutrient agar

Table E2.3 Aerosol Sampling Codes for Pool II.

Pool II

II-1	Dive Tank, side, middle of ladder/board (Nutrient agar)
II-2	Dive Tank, side, middle of ladder/board (Rose Bengal)
II-3	Wave Pool, left side-3ft deep, middle (Nutrient agar)
II-4	Wave Pool, left side-3ft deep, middle (Rose Bengal)
II-5	Wave Pool, no waves (Nutrient agar)
II-6	Wave Pool, no waves (Rose Bengal)
II-7	Kiddy Pool, sparkling end (Nutrient agar)
II-8	Kiddy Pool, sparkling end (Rose Bengal)
II-9	Hot Tub χ (Nutrient agar)
II-10	Hot Tub χ (Rose Bengal)
II-11	Guard Tower (Nutrient agar)
II-12	Guard Tower (Rose Bengal)
II-13	Dive Tank (Nutrient agar)
II-14	Dive Tank (Rose Bengal)
II-15	Bird Cage (Rose Bengal)
II-16	Bird Cage (Nutrient agar)
II-17	Wave Pool (Nutrient agar)
II-18	Wave Pool, no waves (Rose Bengal)
II-19	Kiddie Slide Pool (Rose Bengal)
II-20	Kiddie Slide Pool (Nutrient agar)
II-21	Guard Tower (Nutrient agar)
II-22	Guard Tower, waves (Rose Bengal)

Table E2.4 Microbial Results for the Air Phase at Pool II on December 12, 1990.

Sample Code	Time of Day	Bather Load	Bacteria	Fungi	Actinomycete	Yeasts
			cfu/m^3	cfu/m^3	cfu/m^3	cfu/m^3
II-1 (NA)	09:51	0	19	0	0	0
II-2 (RB)	10:01	0	0	0	0	0
II-3 (NA)	10:14	2	306	13	0	0
II-4 (RB)	10:25		0	0	0	0
II-5 (NA)	10:41	3	28	0	0	0
II-6 (RB)	10:52	2	0	0	0	0
II-7 (NA)	11:05		103	0	0	0
II-8 (RB)	11:16	6	0	0	0	0
II-9 (NA)	11:32	24	234	19	3	0
II-10 (RB)	11:43	24	0	59	0	0
II-11 (NA)	11:54		59	16	0	0
II-12 (RB)	12:04		0	116	0	0
II-13 (NA)	13:38	9	125	3	0	0
II-14 (RB)	13:28	31	0	47	0	3
II-15 (RB)	13:51		0	13	0	0
II-16 (NA)	14:01		84	0	0	0
II-17 (NA)	14:15	35	150	9	0	0
II-18 (RB)	14:22	26-11	0	38	0	0
II-19 (RB)	14:32	6	0	13	0	0
II-20 (NA)	14:42	6	116	31	0	0
II-21 (NA)	15:03	2	350	13	0	0
II-22 (RB)	16:53	2	0	19	0	78

RB: Rose Bengal agar
NA: Nutrient agar

Table E2.5 Aerosol Sampling Codes for Pool III.

Pool III

III-1	Shallow end, Bulkhead (Rose Bengal)
III-2	Shallow end, Bulkhead (Nutrient agar)
III-3	Middle section, Bulkhead deep end/middle (Rose Bengal)
III-4	Middle section, Bulkhead deep end/middle (Nutrient agar)
III-5	Deep end, middle pool end by diving board end (Nutrient agar)
III-6	Shallow end, Bulkhead (Rose Bengal)
III-7	Shallow end, Bulkhead (Nutrient agar)
III-8	Middle section, poolside/middle by bench (Nutrient agar)
III-9	Middle section, poolside/middle by bench (Rose Bengal)
III-10	Deep end, Bulkhead (Rose Bengal)
III-11	Deep end, Bulkhead (Nutrient agar)
III-12	Deep end, middle pool end by diving board end (Rose Bengal)

Table E2.6 Microbial Results for the Air Phase at Pool III on December 5, 1990.

Sample Code	Time of Day	Bather Load	Bacteria	Fungi	Actinomycete	Yeasts
			cfu/m^3	cfu/m^3	cfu/m^3	cfu/m^3
III-1 (RB)	09:38	0	0	0	0	0
III-2 (NA)	09:48	0	81	0	3	0
III-3 (RB)	10:00	2	0	0	0	0
III-4 (NA)	10:10	3	450	13	0	0
III-5 (NA)	10:34	1 (+kayak)	6	0	0	0
III-6 (RB)	11:38	6	0	11	0	0
III-7 (NA)	11:50	6	138	19	0	0
III-8 (NA)		6	166	0	0	0
III-9 (RB)		5	0	16	0	0
III-10 (RB)	15:25	3	0	13	0	6
III-11(NA)	15:41	0	94	0	0	0
III-12 (RB)			0	3	0	0

RB: Rose Bengal agar
NA: Nutrient agar

APPENDIX E3

Microbial Identification at Each Individual Facility
and
Commonly Reported Clinical Manifestation

Table E3.1 Microbial Identification for Facility I Based on November 29, 1990 Sampling.

Tank *	T_0	T_1	T_2
A	*E. coli*		*E. coli* *E. aerogenes* *C. freundii*
B	*E. coli* *E. aerogenes* *E. cloacae* *C. freundii* *K. pneumoniae* *P. vulgaris* *S. marcescens* *Acinetobacter* species	*E. coli* *E. cloacae* *E. tarda* *K. pneumoniae* *K. rhinoscleromatis* *P. vulgaris*	*E. coli* *E. cloacae* *K. ozonae*
C	*E. coli* *Cedacae* species *C. diversus* *C. freundii* *E. cloacae* *Hafnia alvei* *K. oxytoca* *Y. enterocolitica* *A. hydrophila*	*E. coli* *E. cloacae*	*E. coli* *C. freundii* *K. ozonae* *K. pneumoniae*
D	*E. coli* *C. freundii* *C. diversus* *E. agglomerans* *E. cloacae* *Tatumella* species *A. hydrophila* *S. faecalis*	*E. coli* *C. freundii* *E. cloacae* *K. oxytoca* *K. ozonae*	*E. coli* *E. agglomerans* *C. freundii* *K. pneumoniae* *Y. entercolitica* *S. faecalis*
E	*E. coli* *E. agglomerans* *E.cloacae* *C. diversus* *K. ozonae* *K. pneumoniae* *Tatumella* species *A. hydrophila* *S. faecalis*	*E. coli* *E. cloacae* *C. diversus*	*E. coli* *E. cloacae* *C. freundii* *K. pneumoniae* *K. oxytoca*

* Representative colonies were subcultured, purified and then identified. Results are qualitative and meant to illustrate the diversity of genera and species present.

Table E3.2 Microbial Identification for Facility II Based on December 12, 1990 Sampling.

Tank	T_0	T_1
α		*E. coli* *E. agglomerans* *S. faecalis*
β	*Pseudomonas* species *P. aeruginosa* *S. aureus* *Acinetobacter* species	*E. coli* *E. cloacae* *E. agglomerans* *C. freundii* *K. oxytoca* *K. ozonae* *P. vulgaris* *Serratia marcescens* *Tatumella* species *S. faecalis* *Acinetobacter* species
χ	*S. aureus* *S. faecalis*	*Pseudomonas species* *S. aureus*
δ	*E. coli* *E. agglomerans* *C. freundii* *K. pneumoniae* *Pseudomonas* species *Vibrio* species *Y. entercolitica*	*E. coli* *C. freundii* *E. agglomerans* *K. pneumoniae* *S. faecalis*

Table E3.3 Microbial Identification for Facility III Based on December 5, 1990 Sampling.

Tank	T_0	T_1	T_2
X	*E. coli*	*K. oxytoca* *P. aeruginosa* *S. faecalis* *S. faecium*	*E. coli* *E. cloacae* *A. agglomerans* *C. freundii* *K. ozonae* *K. oxytoca* *K. pneumoniae* *P. aeruginosa* *S. faecalis* *S. faecium*
Y	*E. coli* *K. ocytoca* *K. pneumoniae* *P. aeruginosa* *S. faecalis*	*E. coli* *E. cloacae* *E. agglomerans* *C. freundii* *K. ozonae* *K. pneumoniae* *P. vulgaris* *S. faecalis* *S. faecium* *A. hydrophila*	*E. coli* *E. cloacae* *C. freundii* *K. oxytoca* *A. hydrophila*
Z	*S. marcescens* *P. vulgaris* *S. faecalis*	*E. coli* *E. cloacae* *E. agglomerans* *K. oxytoca* *S. faecalis* *A. hydrophila*	*E. coli* *C. freundii* *K. oxytoca* *K. pneumoniae* *P. aeruginosa* *S. faecalis*

Table E3.4 Some Properties of Microorganisms Isolated from Pools.

ORGANISM	Coliform	Endotoxin Production	Histamine Production	Human Carriage	Commonly Reported Clinical Manifestations
**Acinetobacter* species		+		+	Urethritis, Occular infection
Aeromonas hydrophila		+	+		Wound infection, Gastrointestinal infection, Septicemia
**Cedecae* species	+	+			Nosocomial infection (pathogenicity not well known)
**Citrobacter diversus*	+	+		+	Urinary tract infection, Sepsis, Bacteremia
**Citrobacter freundii*	+	+		+	Urinary tract infection, Sepsis, Bacteremia
**Enterobacter agglomerans*	+	+		+	Genitourinary infection, Septicemia, Soft tissue infection, Gastrointestinal infection, neonatal meningitis
**Enterobacter cloacae*	+	+		+	Genitourinary infection, Septicemia, Soft tissue infection, Gastrointestinal infection, neonatal meningitis
**Escherichia coli*	+	+		+	Genitourinary infections, Gastrointestinal infection, Septicemia, Bacteremia
Hafnia alvei		+			Septicemia
**Klebsiella oxytoca*	+	+		+	Pulmonary infection, Gastrointestinal. infection,Genitourinary infection
**Klebsiella ozonae*	+	+		+	Pulmonary infection, Gastrointestinal. infection,Genitourinary infection
**Klebsiella pneumophila*	+	+		+	Pulmonary infection, Gastrointestinal. infection,Genitourinary infection
**Pseudomonas aeruginosa*		+	+		Genitourinary infection, Septicemia, Gastrointestinal infection, Folliculitis, Otitis, Occular infection
**Proteus vulgaris*		+		+	Urinary Tract infections, Septicemia
**Serratia marcescens*	+	+		+	Cystitis, Nosocomial infection
**Staphylococcus ureus*				+	Skin infections, Gastrointestinal infections, Bacteremia
**Streptococcus faecalis*				+	Septicemia, Bacteremia, Wound infections
**Streptococcus faecium*				+	Septicemia, Bacteremia, Wound infections
Tatumella species		+		?	?
Vibrio species		+	+		Gastrointestinal infection
Yersiaia enterocolitica		+			Gastrointestinal infection,

* Opportunisitc Human Pathogen